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TO THE THEORY OF NEUTRINO OSCILLATION

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The example of K^0-, $\bar{K}^0$-meson oscillations is utilized in showing that ν_e, ν_μ, ν_τ oscillations must proceed via two stages. First ν_e, ν_μ, ν_τ-eigenstates of the weak interactions are created. Then, owing to the presence of lepton number violating interactions, these neutrino states are converted into superpositions of ν_1, ν_2, ν_3-eigenstates of interactions violating the lepton numbers. Further, neutrino oscillations will occur in accordance with the standard scheme.

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

К теории осцилляции нейтрино

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На примере K^0-, $\bar{K}^0$-осцилляций показано, что ν_e-, ν_μ-, ν_τ-осциляции идут через две стадии. Сперва рождаются ν_e-, ν_μ-, ν_τ-нейтрино — собственные состояния слабого взаимодействия. Затем, если присутствует взаимодействие, нарушающее лептонные числа, эти нейтринные состояния превращаются в суперпозиции ν_1-, ν_2-, ν_3-нейтрино — собственные состояния взаимодействия, нарушающего лептонные числа. Далее осцилляция нейтрино будет происходить согласно стандартной схеме.

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1. Introduction

In the old theory of neutrino oscillations [1], constructed by analogy with the theory of K^0, $\bar{K}^0$ oscillation, it is supposed that mass eigenstates are ν_1, ν_2, ν_3 neutrino states, but not physical neutrino states ν_e, ν_μ, ν_τ and that the neutrinos ν_e, ν_μ, ν_τ are created as superpositions of ν_1, ν_2, ν_3 states. This means that the ν_e, ν_μ, ν_τ neutrinos have no definite mass, i.e., their masses may vary depending on the ν_1, ν_2, ν_3 admixture in the ν_e, ν_μ, ν_τ states (naturally, in this case the momentum of the neutrinos is not conserved) Probably, this picture is incorrect one. This can be illustrated taking advantage of the K^0, $\bar{K}^0$ oscillations which have been well studied.

2. K^0, $\bar{K}^0$ Oscillations

1) The K^0, $\bar{K}^0$ mesons, which consist of the s, $\bar{s}$, d, $\bar{d}$ quarks, are created in the strong interactions (the typical times of strong interactions are $t_{\text{str}} \cong 10^{-23}$ s.) and are, accordingly, eigenstates of these interactions, i.e., the mass matrix of the K^0, $\bar{K}^0$ mesons is diagonal.

2) If we take into account the weak interaction (typical times of weak interactions are $t_{\text{weak}} \cong 10^{-8}$ s.) which violates strangeness, then the mass matrix of K^0-mesons will become nondiagonal. If we diagonalize this matrix, then we will come to the K_1^0, K_2^0 states, which are eigenstates of the weak interaction [2].

So we can see that, if K^0 mesons are created in strong interactions, then K^0, $\bar{K}^0$ mesons are produced, and if K^0 mesons are created in weak interactions then K_1^0, K_2^0 mesons are created. In these cases no oscillations of K^0 mesons will occur.

3) Now let us give a phenomenological description of K^0, $\bar{K}^0$ meson creation and oscillation processes. We will consider the creation of K^0, $\bar{K}^0$ mesons as a quasistationary process with a typical time t_{str}. Within this typical time, $-t_{\text{str}}$, weak interactions will violate strangeness and result in the mass matrix of the K^0 mesons becoming nondiagonal. The probability for this process to occur in $t = \pi t_{\text{str}}$ is:

$$W(t = \pi t_{\text{str}}) = \frac{\left(1 - \exp\left(-\frac{t}{t_{\text{weak}}}\right)\right)}{\left(1 - \exp\left(-\frac{t}{t_{\text{str}}}\right)\right)} \cong \\ \cong \pi \frac{t_{\text{str}}}{t_{\text{weak}}} \cong \pi\, 10^{-15}, \qquad (1)$$

where $\left(1 - \exp\left(-\frac{t}{t_{\text{str, weak}}}\right)\right)$ — is the decay probability of the quasistationary state during the time — t.

The mass matrix of the K^0 mesons will become nondiagonal in $t = \pi\, 10^{-23}$ s with a probability of $W \cong \pi\, 10^{-15}$. And then the K_1^0, K_2^0 mesons — eigenstates of weak interactions will be created. So we can see that in this case mainly K^0, $\bar{K}^0$ mesons will be produced, but not the K_1^0, K_2^0 mesons.

Then, when the K^0, $\bar{K}^0$ mesons, that were created in strong interactions, pass through vacuum, the mass matrix of the K^0 mesons will become nondiagonal, owing to the presence of weak interactions violating strangeness. Diagonalizing it, we get K_1^0, K_2^0-meson states which are eigenstates of weak interactions. Obviously, the K^0, $\bar{K}^0$ mesons are, then, converted into superpositions of K_1^0, K_2^0 mesons [2].

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

Then, oscillations of the K^0, $\overline{K}^0$ mesons will take place on a background of K_1^0, K_2^0 decays. The length of these oscillations is [3]:

$$L_{\text{osc}}(m) = \frac{2.48 p_{K^0}\,(\text{MeV})}{|m_{K_1^0 K_1^0} - m_{K_2^0 K_2^0}|^2\,(\text{eV})^2}, \tag{3}$$

p_{K^0} is the momentum of K^0.

The main question which arises now is: which type of oscillations — real (implying actual transitions between the particle) or virtual (implying virtual transitions between particle without transition to mass shells) takes place between the K^0, $\overline{K}^0$ mesons? Since the masses of K^0 and $\overline{K}^0$ mesons are equal, oscillations between these mesons are real. But, if the masses of K^0 and $\overline{K}^0$ mesons were not equal, then the oscillations would be virtual [4].

3. ν-Oscillations

We can now pass to the analysis of neutrino oscillations, taking advantage of the example of K^0, $\overline{K}^0$-meson oscillations.

1) The physical states of the ν_e, ν_μ, ν_τ neutrinos are eigenstates of the weak interaction and, naturally, the mass matrix of ν_e, ν_μ, ν_τ neutrinos is diagonal. All the available experimental results indicate that the lepton numbers l_e, l_μ, l_τ are well conserved, i.e., the standard weak interactions do not violate the lepton numbers.

2) Then, to violate the lepton numbers, it is necessary to introduce an interaction violating these numbers. It is equivalent to indroducing nondiagonal mass terms in the mass matrix of ν_e, ν_μ, ν_τ. Diagonalizing this matrix we go to the ν_1, ν_2, ν_3 neutrino states. Exactly like the case of K^0 mesons creating in strong interactions, when mainly K^0, $\overline{K}^0$ mesons are produced, in the considered case ν_e, ν_μ, ν_τ, but not ν_1, ν_2, ν_3, neutrino states are mainly created in the weak interactions (this is so, because the contribution of the lepton numbers violating interactions in this process is too small).

3) Then, when the ν_e, ν_μ, ν_τ neutrinos pass through vacuum, they will be converted into superpositions of the ν_1, ν_2, ν_3 owing to presence of the interactions violating the lepton numbers of neutrinos and will be left on their mass shells. And, then, oscillations of the ν_e, ν_μ, ν_τ neutrinos will take place according to the standard scheme [1]. Whether these oscillations are real or virtual will be determined by the masses of the physical neutrinos

ν_e, ν_μ, ν_τ. i) If the masses of the ν_e, ν_μ, ν_τ neutrinos are equal, then real oscillation of the neutrinos will take place. ii) If the masses of the ν_e, ν_μ, ν_τ are not equal, then virtual oscillation of the neutrinos will take place. To make these oscillations real, these neutrinos must participate in the quasielastic interactions, in order to undergo transition to the mass shell of the other appropriate neutrinos by analogue with γ — ρ^0 transition in the vector meson dominance model. In case ii), enhancement of neutrino oscillations will take place if the neutrinos pass through a bulk of matter [5].

References

1. Boehm F., Vogel P. — Cambridge Univ. Press, 1987, p.27, p.121.
   Bilenky S.M., Petrov S.T. — Rev. of Mod. Phys., 1987, 59, p.631.
2. Beshtoev Kh.M. — Turk. Journ. of Phys., 1994, 18, p.787.
3. Okun L.B. — Leptons and Quarks, M., 1990.
4. Beshtoev Kh. M. — JINR, E2-92-318, Dubna, 1992.
5. Beshtoev Kh.M. — JINR, E2-94-46, Dubna, 1994.

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