## On the Energy Spectrum of $\mu$-Mesons from $K_{\mu 3}$ Decay

S. G. MATINIAN
*Institute of Physics*
*Academy of Sciences of the Georgian SSR*
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IN A PREVIOUS COMMUNICATION[1] concerning the problem of $K_{\mu 3}$ decay ($K^{\pm}_{\mu 3} \to \mu^{\pm} + \nu + \pi^0$) the energy spectrum of the $\mu$-mesons from $K_{\mu 3}$ decay was calculated for the case of a scalar (pseudoscalar) particle with directly coupled fields. In the present note we consider decay of the same particle, but with derivative coupling between the fermion ($\mu$, $\nu$) and spin-0 boson ($K_{\mu 3}$, $\pi$) fields.

The interaction Hamiltonian is of the form

$$H' = f m_\pi^{-2} (\overline{\psi}_\mu \gamma \gamma_i \psi_\nu)(\partial/\partial x_i)(\overset{*}{\varphi}_\pi \varphi_K) \quad (\hbar = c = 1). \quad (1)$$

Here $f$ is a dimensionless coupling constant, $m_\pi$ is the mass of the $\pi$-meson, $\psi$ is a spinor, and $\varphi$ is a scalar wave function; $\gamma$ is equal to unity or $\gamma_5$, depending on the parity of the $K_{\mu 3}$-meson.

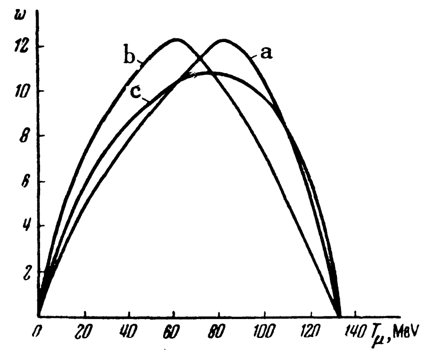
Carrying through the calculation similarly as previously[1] we obtain the following expression for the differential decay probability of the $K_{\mu 3}$-meson at rest:

$$w dE_\mu = \frac{f^2}{32\pi^3 m_\pi^2} \frac{(A - 2ME_\mu)\sqrt{E_\mu^2 - m_\mu^2}}{M(B - 2ME_\mu)^2} \times$$
$$\times \{m_\pi^{-2}(A - 2ME_\mu)(H - 2ME_\mu)(ME_\mu - m_\mu^2) \quad (2)$$
$$- C - DE_\mu + 2M^2 E_\mu^2\} dE_\mu.$$

Here $H = M^2 + m_\mu^2 + m_\pi^2$, with the remaining notation being the same as that used previously[1].

We note that, as before, we have obtained a result which is independent of the $K_{\mu 3}$ parity: the decay probability of the scalar meson with scalar (vector) coupling is equal to the decay probability of the pseudoscalar meson with pseudoscalar (pseudovector) coupling[2]. This is clearly related to the zero mass of the neutrino.

Lee and Yang[3] and Morpurgo[4] have given experimental data on the $\mu$-meson spectrum from $K_{\mu 3}$ decay. A characteristic of the results is the large number of low-energy $\mu$-mesons. The maximum energy of the $\mu$-meson spectrum given by Lee and Yang[3] is in the region of $T_\mu \approx 40$ Mev (where $T_\mu$ is the kinetic energy of the $\mu$-mesons), whereas the spectrum corresponding to their phase volume has a maximum in the region of $T_\mu \approx 75$ Mev. According to our calculations the maximum in the spectrum lies in the region of 85 Mev for direct coupling, which is in disagreement with the experimental data. For derivative coupling, the $\mu$-meson spectrum has a maximum at 60 Mev, which is in better agreement with experiment. The Figure shows the $\mu$-meson spectra for (a) direct coupling and (b) derivative coupling of the fields. Also shown is the spectrum corresponding to the $\mu$-meson phase volume (c). The spectra are given in arbitrary units and the curves are normalized to unit area.




Energy spectra of $\mu$-mesons from $K_{\mu 3}$ to $K$.

It should be noted that the $\mu$-meson energy spectrum from $K_{\mu 3}$ decay has not yet been accurately measured. It is difficult to differentiate between fast $\mu$-mesons ($T_\mu \approx 100$ Mev) from $K_{\mu 3}$ decay and $\pi$-mesons from $K_{\pi 2}$ decay and $\mu$-mesons from $K_{\mu 2}$ decay.

The fact that vector (pseudovector) coupling is in better agreement with experiment may also be due to the following situation. As is well known, only vector (pseudovector) coupling gives the correct relation between the probabilities for $\pi \to \mu$ and $\pi \to e$ decays[5,6]. If we use the universal meson-lepton interaction[2], the same coupling must be used for $K_{\mu 2}$ decay (as is well known, the decay $K_{e2} \to e + \nu$ is not observed in experiment). Then the Hamiltonian of Eq. (1) for $K_{\mu 3}$ decay would seem to be reasonable if we consider the $K_{\mu 3}$-meson and the $K_{\mu 2}$-meson to be coupled through the $\pi$-field[1].

We note that at present there is no reason to assume the spin of the $K$-mesons to be nonzero. If, nevertheless, the spin of the $K_{\mu 3}$ is found to be different from zero, there may be a correlation between the spins of the $K_{\mu 3}$ and the $\mu$ in the decay of polarized $K_{\mu 3}$ particles.

The following Hamiltonians may be responsible for the decay of a vector $K_{\mu 3}$-meson at rest:

$$H_1' = g_1(\overline{\psi}_\mu \psi_\nu) A_i \partial\varphi_\pi/\partial x_i, \quad H_2' = g_2(\overline{\psi}_\mu \gamma_i \psi_\nu) A_i \varphi_\pi,$$

$$H_3' = g_3(\overline{\psi}_\mu \gamma_i \gamma_k \psi_\nu) A_i \partial\varphi_\pi/\partial x_k,$$

where $A_i$ is the vector wave function of the $K_{\mu 3}$-meson. If we calculate the probability for emission of polarized $\mu$-mesons in the decay of spin-1 polarized $K_{\mu 3}$-mesons as was done by Okun',[7] we obtain the following results. The interactions $H_i'$ separately do not lead to polarized $\mu$-mesons. Neither does the "mixture" $H_i' + H_3'$. The "mixtures" $H_1' + H_2'$ and $H_2' + H_3'$, on the other hand, lead in general to polarized $\mu$-mesons.

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## On Strong Interaction between the $K$-Particle and the $\pi$-Particle

S. G. MATINIAN
*Institute of Physics*
*Academy of Sciences of the Georgian SSR*

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EXPERIMENTAL DATA concerning $K$-mesons lead to two different conclusions which are difficult to reconcile. On the one hand, experiment gives the same (within the limits of experimental error) masses and lifetimes for different $K$-particles. In experiments performed under varying conditions, different $K$ decay schemes are observed with equal frequency[1]. In addition, experiments with a beam of $K^+$-mesons before and after scattering[2] lead to the conclusion that the $\theta$ and $\tau$-particles have the same interaction cross sections with matter. All this would seem to imply that the different $K$-meson decay schemes correspond to alternate modes of decay for the same particle. On the other hand, analysis of $\tau$-decays and the existence of the $\theta^0 \to 2\pi^0$ decay implies that the $\theta$ and $\tau$ are different particles.

In order to eliminate this contradiction, Lee and Yang introduced the concept of parity doublets[3] and parity nonconservation in weak interactions[4]. Schwinger postulated a strong interaction between pions and $K$-mesons. In the present note the hypothesis of a strong $\pi$-$K$ interaction is applied to obtaining certain relations between the probabilities of $K$ decays according to various schemes.

We thus start from the following isotopic invariant interaction scheme between the $\pi$- and $K$-mesons.

$$K' \rightleftarrows K'' + \pi. \tag{1}$$

On the basis of Eq. (1) we may relate, for instance, the decay of the $\tau$-meson with the decay of the $\theta$-meson, and determine, in particular, the ratio of the probabilities for the two decays

$$\tau^{\pm\prime}(\to 2\pi^0 + \pi^\pm) \text{ and } \tau^\pm(\to \pi^+ + \pi^- + \pi^\pm).$$

According to (1) we may write the $\tau^+$ decay

$$\tau^+ \xrightarrow{g_{K\pi}} \pi^+ + \theta^0 \xrightarrow{f} \pi^+ + \pi^+ + \pi^-, \tag{2}$$

where $g_{K\pi}$ is the coupling constant of the strong $\pi$-$K$ interaction, and $f$ is the coupling constant of the weak interaction between the $\theta$-field and the $\pi$-field. For the $\tau^{+\prime}$ decay we have two possibilities:

$$\tau^{+\prime} \xrightarrow{g_{K\pi}} \begin{cases} \pi^+ + \theta^0 \xrightarrow{f} \pi^+ + \pi^0 + \pi^0, \\ \pi^0 + \theta^+ \xrightarrow{f} \pi^0 + \pi^0 + \pi^+. \end{cases} \tag{2'}$$

The probability of one or another $\tau$ decay is given by the product of the probability for formation of one or another $\pi + \theta$ configurations (this