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INTERPRETATION OF EXPERIMENTS ON THE SEARCHES FOR THE $K_S \to 2\mu$ DECAY

A.D. Dolgov, V.I. Zakharov, and L.B. Okun'
Institute of Theoretical and Experimental Physics, USSR Academy of Sciences

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In connection with the contradiction between the results of experiments on the decays $K_L \to 2\mu$ [1] and $K_L \to 2\gamma$ [2], a hypothesis was advanced [3, 4], according to which the suppression of the $K_L \to 2\mu$ decay is due to destructive interference of the $K_2 \to 2\mu$ and $K_1 \to 2\mu$ transitions. The width of the $K_S \to 2\mu$ decay should in this case be relatively large [4]. $\Gamma_S^\mu \geq 1.7 \times 10^{-7}\Gamma_S$. As is implied in [4] and discussed explicitly in [5], this lower limit is attainable only in the presence of a strong $2\pi - 2\mu$ interaction. We shall discuss below the possibility that this interaction is CP-noninvariant and analyze the limitations imposed on the width of the $K_S \to 2\mu$ decay under different hypotheses concerning the anomalous interactions of muons, photons, and pions.

We assume in accordance with the experiments of [1, 2] and with the definitions of Γ and T [3, 4] that

$$\Gamma_L^\mu = |T_2^{\mu+} + \epsilon T_S^{\mu+}|^2 + |T_2^{\mu-} + \epsilon T_S^{\mu-}|^2 \leqslant \bar{\Gamma}_L^\mu = 1.8\cdot 10^{-9}\Gamma_L, \tag{1}$$

$$\Gamma_L^\gamma = |T_2^{\gamma+} + \epsilon T_S^{\gamma+}|^2 + |T_2^{\gamma-} + \epsilon T_S^{\gamma-}|^2 = 5\cdot 10^{-4}\Gamma_L. \tag{2}$$

The indices L and S pertain to K_L and K_S, the indices 1 and 2 to K_1 and K_2, and the indices μ and γ to the states 2μ and 2γ, while $\pm$ stands for CP = +1 and -1, respectively:

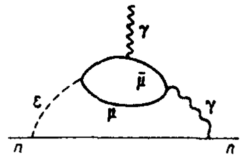
$$K_{L,S} = K_{2,1} + \epsilon K_{1,2},$$
$$\epsilon = |\epsilon| e^{i\phi_\epsilon} \approx 2\cdot 10^{-3} e^{i45^\circ}.$$

Let us consider a few possibilities.

1) Let the $K_L \to 2\gamma$ decay be CP-invariant: $T_2^{\gamma+} = T_2^{\mu+} = 0$. Then $|\mathrm{Im}\, T_2|^2 = 1.2 \times 10^{-5}\Gamma_L^\gamma = 6 \times 10^{-9}\Gamma_L$ [4], and it follows from (1) that [3, 4]

$$\Gamma_S^\mu \geqslant |T_S^{\mu-}|^2 \geqslant (\sqrt{1.2\cdot 10^{-5}\Gamma_L^\gamma} - \sqrt{\bar{\Gamma}_L^\mu})^2 / |\epsilon|^2 \cos^2(\phi_\epsilon + \phi_S^{\mu-}), \tag{3}$$

where $\phi_S^{\mu-} = \arg T_S^{\mu-}$.



We write the effective Lagrangian of the CP-noninvariant $2\pi - 2\mu$ interaction in the form

$$\frac{c_-}{m_K}(\phi_\pi \phi_\pi)\bar{\mu}\gamma_5 \mu . \qquad (4)$$

If $c_- = 0$, then $\phi_S^{\mu-} = \pm\pi/2$ and from (3) we get $\Gamma_S^\mu \geq 10^{-6}\Gamma_S$ [6, 7]. If $\phi_S^{\mu-} = -\phi_\varepsilon$, then $\Gamma_S^\mu \geq 5 \times 10^{-7}\Gamma_S$. From the unitarity condition we then obtain:

$$c_-^2 = \frac{256\pi^2 \sin^2\phi_S^{\mu-}}{3v_\pi v_\mu} \frac{\Gamma_S^\mu}{\Gamma_S} . \qquad (5)$$

Here $v_\pi = 0.833$ and $v_\mu = 0.9$ are the velocities of the π and μ mesons in the decays $K^0 \to 2\pi$ and $K^0 \to 2\mu$. At $\phi_S^{\mu-} = 45°$ and $\Gamma_S^\mu/\Gamma_S = 5 \times 10^{-7}$, relation (5) yields $c_-^2 = 3 \times 10^{-4}$.

The interaction (4) should yield a neutron dipole moment on the order of $(10^{-19} - 10^{-21})\, e\hbar/mc$ (see the figure), which is larger by 2 - 4 orders of magnitude than admitted by experiment [8]. In addition, P- and T-odd correlations should appear in elastic μp scattering of the type $[\vec{\zeta}_1 \times \vec{\zeta}_2]\cdot\vec{p}$ or $(\vec{\zeta}\cdot\vec{p}_1)(\vec{\zeta}\cdot[\vec{p}_1 \times \vec{p}_2])$, which would best appear at $E_\mu \simeq 1$ GeV.

2) Let the $K_L \to 2\gamma$ be CP-noninvariant, $T_2^{\gamma-} = T_2^{\mu-} = 0$. Then $|\mathrm{Im}\, T_2^{\mu+}|^2 = 1 \times 10^{-5}\Gamma_L^\gamma = 5 \times 10^{-9}\Gamma_L$ [3, 4], and from (1) it follows that

$$\Gamma_S^\mu \geqslant |T_S^{\mu+}|^2 \geqslant \left(\sqrt{1\cdot 10^{-5}\Gamma_L^\gamma} - \sqrt{\bar{\Gamma}_L^\mu}\right)^2 \Big/ |\epsilon|^2 \cos^2(\phi_\epsilon + \phi_S^{\mu+}), \qquad (6)$$

where $\phi_S^{\mu+} = \arg T_S^{\mu+}$.

We write down the effective Lagrangian of the CP-invariant $2\pi \to 2\mu$ interaction

$$\frac{c_+}{m_k}(\phi_\pi \phi_\pi)\bar{\mu}\mu . \qquad (7)$$

If $c_+ = 0$, then $\phi_S^{\mu+} = 0$ and from (6) we have $\Gamma_S^\mu \geq 6 \times 10^{-7}\Gamma_S$. If $\phi_S^{\mu+} = -45°$, then $\Gamma_S^\mu \geq 3 \times 10^{-7}\Gamma_S$. We then obtain from the unitarity condition

$$c_+^2 = \frac{256\pi^2 \sin^2\phi_S^{\mu+}}{3v_\pi v_\mu^3} \frac{\Gamma_S^\mu}{\Gamma_S} , \qquad (8)$$

which at $\phi_S^{\mu+} = 45°$ and $\Gamma_S^\mu/\Gamma_S = 3 \times 10^{-7}$ yields $c_+^2 = 2 \times 10^{-4}$, which agrees with the result [5].

3) We have assumed so far that $\Gamma_S^\gamma \simeq \Gamma_L^\gamma$ or $\varepsilon\sqrt{(\Gamma_S^\gamma)} \ll \sqrt{(\Gamma_L^\gamma)}$. On the other hand, if Γ_S^γ is anomalously large and is close to its upper limit [9], $\Gamma_S^\gamma = 1.2 \times 10^{-5}\Gamma_S$, then the lower limit for $\mathrm{Im}\, T_2^{\mu+}$ becomes smaller:

$$|\mathrm{Im}\, T_2^{\mu +}| \geq \sqrt{10^{-5}\Gamma_L^\gamma}\,[1 - |\epsilon| \cos(\phi_\epsilon + \phi_{LS}^\gamma)]\sqrt{\Gamma_S^\gamma/\Gamma_L^\gamma}\,, \qquad (9)$$

where $\phi_{LS}^\gamma = \arg [T_L(T_S)^*]$. If $\Gamma_S^\gamma = 1.2 \times 10^{-3}\Gamma_S = 0.72\Gamma_L$, then at $\phi_{LS}^\gamma = 0$ we have $|\mathrm{Im}\, T_2^{\mu +}| \geq 0.95\sqrt{(10^{-5}\Gamma_L^\gamma)}$, and at $\phi_{LS}^\gamma = -45°$ we have $|\mathrm{Im}\, T_2^{\mu +}| \geq 0.93\sqrt{(10^{-5}\Gamma_L^\gamma)}$. The first of these values of $|\mathrm{Im}\, T_S^{\mu +}|$ corresponds to $\Gamma_S^\mu \geq 2.5 \times 10^{-7}$, and the second to $\Gamma_S^\mu \geq 2.1 \times 10^{-7}$. In order to reach the latter limits it is necessary to have: a) CP violation in the $K_L \to 2\gamma$ decay, b) an anomalously large probability of $K_S \to 2\gamma$, c) an anomalously strong $2\pi - 2\mu$ interaction, d) an anomalously strong $2\pi \to 2\gamma$ interaction. The simultaneous occurrence of these four anomalies is extremely unlikely.

If $\Gamma_L^\gamma = 4 \times 10^{-4}$, which does not contradict any of the experiments [2], then the possibilities (1), (2), and (3), correspond to lower limits $\Gamma_S^\mu/\Gamma_S \geq 2.9 \times 10^{-7}$, 1.8×10^{-7}, and 1.1×10^{-7}, respectively. The best of the published results is $\bar{\Gamma}_S^\mu = 7 \times 10^{-6}\Gamma_S$ [10]. As reported by Professor Kleinknecht, a preliminary result $\bar{\Gamma}_S^\mu = 1.5 \times 10^{-6}\Gamma_S$ was obtained at CERN.

A detailed analysis, the results of which will be published separately, shows that strong $2\pi - 2\mu$ interaction (7) does not contradict the available experimental data on the verification of the quantum electrodynamics of the muon, namely g = 2, elastic and inelastic scattering of muons by nucleons, production of muon pairs in collisions of hadrons, and the levels of μ-mesic atoms.

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DETECTION OF FAST PARTICLES BY THE DEFLECTION OF ELECTROMAGNETIC WAVES IN A TRAIN OF EXCITED STATES OF ATOMS ACCOMPANYING THE PARTICLE

M.I. Ryazanov
Moscow Engineering Physics Institute

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1. A particle moving in a substance excites continuously the atoms with which it collides in the substance as it moves. The successive excitation of the immobile atoms along the particle path is equivalent to motion of a "train" of excited atoms. The longitudinal dimensions of the train are determined by the lifetime τ of the excited state, and are macroscopic for relativistic