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CONCERNING THE DECAY $K_L^0 \to \pi^+ + \pi^-$

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1. It was observed in [1] and also in the succeeding experiments [2-4] that, contrary to the theoretical prediction based on the assumed validity of CP invariance,

$$\frac{K_L^0 \to \pi^+ + \pi^-}{K_L^0 \to (\text{all charged channels})} \simeq 2 \times 10^{-3}. \qquad (1)$$

It is interesting to note that in no other experiments for checking CP invariance (in particular, in lepton decays of K^0 [5,6]) were any effects observed of the same order as in the fundamental experiment [1] (a good review of the entire K_L^0 problem is contained in [6]).

We propose here one more idea for explaining the experiments of [1-4], based on the specific character of the creation and decay of K^0, which has no analog for any other elementary particle. The nub of the idea is the following question: Do the properties of unstable particles depend on the method of preparation [7-11] or not?

2. We assume, as usual, that strong interactions create a K^0 which is a coherent mixture of K_1^0 and K_2^0:

$$K^0 = 1/\sqrt{2}\,(K_1^0 + K_2^0), \qquad (2)$$

where K_1^0 and K_2^0 are the eigenstates of the combined-parity operator $CP|K_1^0\rangle = +1\cdot|K_1^0\rangle$, $CP|K_2^0\rangle = -1\cdot|K_2^0\rangle$ which decay (and are also produced in place of K^0) as a result of weak interaction. The energy (mass) distribution of K^0, on the basis of (2), is

$$\rho_{K^0}(E) = \frac{1}{4\pi}\,\frac{\Gamma_1}{(E - E_{K_1^0})^2 + \Gamma_1^2/4} + \frac{1}{4\pi}\,\frac{\Gamma_2}{(E - E_{K_2^0})^2 + \Gamma_2^2/4}, \qquad (3)$$

where $E_{K_1^0}$ and $E_{K_2^0}$ are the energies (masses) of K_1^0 and K_2^0, while Γ_1 and Γ_2 are the corresponding total widths. If K^0 itself were to decay with the same energy distribution as in (3), i.e.,

$$|K^0(t)\rangle = \{1/2\ [\exp[-iB_{K_1^0}t - \frac{\Gamma_1}{2}|t|]] + 1/2\ [\exp[-iE_{K_2^0}t - \frac{\Gamma_2}{2}|t|]]\}|K^0(t = 0)\rangle, \qquad (4)$$

and not K_1^0 and K_2^0 separately (see, e.g., [12]),

$$|K^0(t)\rangle = \{1/2\ \exp[-iE_{K_1^0}t - \frac{\Gamma_1}{2}|t|]|K_1^0\rangle + 1/2\ \exp[-iE_{K_2^0}t - \frac{\Gamma_2}{2}|t|]|K_2^0\rangle\}, \qquad (5)$$

this would contradict the experimental facts, for it would follow from (4) and (2) that a noticeable fraction of K_1^0 would remain even after a long time. On the other hand, the statement that the decay proceeds in accordance with (5), i.e., that K_1^0 and K_2^0 decay independently (separately), calls for the existence of some mechanism that "filters" the energy (mass) distribution of K^0 so as to separate K_1^0 and K_2^0 individually [1]. Arguments for the need for a "mass filter" when considering unstable particles were presented in [7,13], but the influence of this filtering depends greatly on the choice of the assumption made, that the properties of the unstable particles do or do not depend on the preparation [7-11].

In fact, if the properties of unstable elementary particles do not depend on the preparation, and consequently also on the mass filtering, then the filtering will affect only the intensity of the observed effects, but will not change the properties of the unstable particles. Thus, in filtering the K^0 masses to separate the K_2^0, a fraction of the K_1^0 mass distribution will unavoidably pass through (since the distributions of the K_2^0 and K_1^0 masses overlap), but the law governing the decay of these "filtered" K_1^0 will be determined under our assumption by the lifetime of K_1^0, and not by the filtration interval ΔE, and consequently not by the lifetime of K_2^0. That is to say, in this case $K_L^0 \equiv K_2^0$, $K_S^0 \equiv K_1^0$, and the problem of the $K_L^0 \to 2\pi$ decay remains unsolved.

On the other hand, if the properties of the unstable particles (more accurately, of K^0) depend on the preparation, and consequently also on the filtering, the situation changes radically. Indeed, when filtering the K^0 masses to separate K_2^0, we unavoidably must take into account the part of K_1^0 which passes through this mass filter. The law governing the decay of such filtered K_1^0 will under this assumption be already determined not by the lifetime of $K_1^0 = K_S^0$ [2], but by the lifetime of K_2^0, which is connected with the filtering interval $\Delta E \sim \Gamma_2$. Thus, if we assume that the properties of the unstable particles K^0, K_L^0, and K_S^0 depend on the preparation, then K_L^0, which is a decaying state having the same lifetime as K_2^0, will be a mixture of K_2^0 and of K_1^0, i.e., a state with a mixture of states CP = -1 and CP = 1. Consequently the decay products of K_L^0 will also have different CP. This explains qualitatively the $K_L^0 \to \pi^+ + \pi^-$ effect [1-4]. The initial idea reduces thus to the fact that CP invariance is not violated, but by virtue of the specific nature of the creation and decay of K^0 (the mass filtering of K^0) the long-lived state K_L^0 is a mixture of the states K_2^0 and K_1^0, i.e., K_L^0 cannot have a definite combined parity and does not coincide with K_2^0. A quantitative estimate, of course, depends on the details of the mass filter, but gives in order of magnitude precisely the observed value of the $K_L^0 \to \pi^+ + \pi^-$ effect (1). Indeed, if we assume the mass filter to be rectangular with $\Delta E \simeq \sigma\Gamma_2$ and assume [14] that K_2^0 (all charged channels)/K_2^0 (all channels) $\simeq 0.73$, while $K_1^0 \to \pi^+ + \pi^-/K_1^0 \to \pi^0 + \pi^0 \simeq K_1^0 \to \pi^+ + \pi^0/K_1^0$ (all neutral channels) $\simeq 0.7$, and that $\Gamma_2 \ll \Gamma_1$, then

$$\frac{K_L^0 \to \pi^+ + \pi^-}{K_L^0 \to \text{(all charged chan.)}} \simeq \frac{0.7}{0.73} \frac{2\sigma\Gamma_2}{\pi\Gamma_1(1 + 4\delta^2)} \frac{1}{(2/\pi)\arctan\sigma} \simeq \frac{\sigma}{\arctan\sigma} \frac{1}{1 + 4\delta^2} 1.57 \times 10^{-3} \tag{6}$$

where $\delta\Gamma_1 \equiv |E_{K_2^0} - E_{K_1^0}|$. The estimate of σ depends on the exact value of δ, which has not yet been determined with sufficient accuracy [6-14]. If $\delta \simeq 0.2 - 0.5$, then for $\sigma \simeq 1 - 2$ we obtain, in accord with (6), good agreement with (1). More accurately:

$$\frac{K_L^0 \to \pi^+ + \pi^-}{K_L^0 \to \text{(all char. chan.)}} \simeq \frac{0.7}{0.73} \int \frac{1}{2\pi} \frac{\Gamma_1 \mathcal{M}(E) \cdot dE}{(E - E_{K_1^0})^2 + (\Gamma_1^2/4)} \Big/ \int \frac{1}{2\pi} \frac{\Gamma_2 \mathcal{M}(E) \cdot dE}{(E - E_{K_2^0})^2 + \Gamma_2^2/4)}, \tag{7}$$

where $\mathcal{M}(E)$ - energy characteristic of the filter used to separate K_2^0 from K^0.

3. The method indicated for solving the $K_L^0 \to \pi^+ + \pi^-$ problem agrees well with the following known facts: (a) nowhere except in the decay of K_L^0 is there any apparent violation of CP; (b) the effect of filtering is manifest, by virtue of the properties of K_1^0, only in the hadron channel of the decay, and there are no such effects in the lepton channels of K^0 decay [5,6]; (c) there should be no dependence of (1) on the momentum of K_L^0 [3,4]; (d) under condition (b) it is clear that the $K_L^0 \to \pi^+ + \pi^-$ effect does not influence at all the parameters of K_1^0, K_2^0, and K^0, especially $|E_{K_2^0} - E_{K_1^0}|$, determined on the basis of the lepton channels of K^0.

At the same time, the following new effect is predicted:

$$\frac{K_L^0 \to \pi^0 + \pi^0}{K_L^0 \to \text{(all char. chan.)}} \simeq 2 \times 10^{-3} \times \frac{0.3}{0.7} \simeq 0.9 \times 10^{-3}$$

independently of the details of the filtering mechanism. This prediction is fundamental and its experimental verification can decide finally the fate of the proposed method of solving the $K_L^0 \to 2\pi$ problem.

From this point of view it is very important to determine the detailed form of the law of K_L^0 decay (this requires accumulation of statistics), for it will then become possible to determine the orders of the poles [3] describing K_1^0 and K_2^0, [15,16], and to determine the form of the mass filter $\mathcal{M}(E)$. Indeed, a rectangular filter cannot have exceedingly small σ, for then the following condition [7]

$$\frac{\Gamma_2 t \cdot \exp(-\Gamma_2^2 t/2)}{2} \gg \frac{\Gamma_2^2}{\Gamma_2^2 + 4\sigma^2\Gamma_2^2} \tag{8}$$

that the exponential term in the decay of K_L is the principal one would not be satisfied.

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[2] In filtering the masses of K^0 for the separation of K_1^0, by virtue of $\Gamma_1 \gg \Gamma_2$, the filtered K_2^0 will not affect the K_S^0, and $K_S^0 = K_1^0$.

[3] The estimates (6) and (7) are based on the usual assumption that the unstable particles are described by first-order poles.

INFRARED-CONTROLLED FIELD EMISSION FROM GERMANIUM

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In [1] we presented the results of an investigation of field emission from single-crystal Ge doped with Au. We showed that on cooling to liquid-nitrogen temperature, when the resistance of this material becomes high ($\rho \sim 10^6 - 10^8$ ohm-cm), the field-emission current is limited by the volume resistivity of the sample. The voltage-current characteristic of the emission current is of the form

$$I = A \exp(- \frac{V_0}{V - IR}), \tag{1}$$

where R is the resistance of the sample and V_0 some voltage characterizing the given sample,