mental data, both electric and magnetic. This, of course, is highly speculative.

(5) Thus the ρ-π-γ meson-exchange effect appears to be a good candidate for explaining the consistently large magnetic scattering observed at all values of q^2 and the possible enhancement of the electric scattering for $q^2 > 10$ F^{-2}.

We intend to extend our experimental program with further data at q^2 of 16 F^{-2} and possibly 10 F^{-2}.

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TEST FOR PARTICLE-MIXTURE THEORIES OF $K^0 \rightarrow 2\pi$ DECAY

P. K. Kabir

Institut de Physique Nucleaire, Lyon, France

and

R. R. Lewis*

Institut de Physique Theorique, Geneve, Switzerland

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Christenson, Cronin, Fitch, and Turlay[1] have discovered that, in addition to the well-known short-lived 2π mode characterized by the lifetime[2] $\gamma_1^{-1} = (0.92 \pm 0.02) \times 10^{-10}$ sec, there is another $\pi^+\pi^-$-decay mode of neutral K mesons which persists at times of the order of $300\ \gamma_1^{-1}$. The lifetime associated with this second mode has not been measured accurately, but the observations are compatible with what would be expected from a $\pi^+\pi^-$- decay channel of the long-lived mode of K^0 decay $[\gamma_2^{-1} = (5.62 \pm 0.68) \times 10^{-8}$ sec] with a branching ratio of $R = (2.0 \pm 0.4) \times 10^{-3}$ with respect to all charged modes. CP invariance would require R to be strictly zero. This observation of long-lived $\pi^+\pi^-$ decays, which we shall refer to as the LLD effect, has subsequently been confirmed by two other groups[3] who find, under considerably different conditions, values of R which are substantially the same as the one previously reported. However, since there is nothing in the observations which is manifestly noninvariant under CP, and there is no clear indication of CP violation anywhere else, it is important to consider possible explanations of the LLD effect within the framework of CP invariance. In this note we describe a simple test for a class of such theories (particle-mixture theories), which represent the only proposals advanced so far which maintain CP invariance without calling upon cosmological effects.[4]

It is a common feature of all such particle-mixture theories[5-8] that they require the existence of an additional spinless particle state, which we shall denote by $|S\rangle$, with $CP = +1$, in the neighborhood of the K^0-meson mass. This state mixes with the $CP=+1$ component of neutral K mesons, $|K_+\rangle=(|K^0\rangle+|\bar{K}^0\rangle)/\sqrt{2}$, in the same sense that the K^0 mixes with the $\bar{K}^0$ through weak interactions,[9] or the ρ^0 mixes with the ω^0 through electromagnetic interactions.[10] In a Weisskopf-Wigner approximation,[11] the states characterized by an exponential time dependence are linear combinations of $|S\rangle$ and $|K_+\rangle$,

$$|\psi_S\rangle=N(\cos\theta|K_+\rangle+\sin\theta|S\rangle),$$

$$|\psi_L\rangle=N(\sin\theta|K_+\rangle-\sin\theta|S\rangle). \quad (1)$$

Here θ is a complex parameter determined by the energy matrix of the S-K_+ system, and T invariance has been assumed.

$$N^{-2}=|\cos\theta|^2+|\sin\theta|^2=\cosh2\chi,$$

where

$$\theta=\varphi+i\chi.$$

Since CP invariance is postulated, there is no mixing of the $CP=-1$ component, $|K_-\rangle=(|K^0\rangle-|\bar{K}_0\rangle)/\sqrt{2}$, with $|\rho\rangle$ and $|K_+\rangle$.

(1) According to this picture, when a K^0 or a $\bar{K}^0$ is produced, its K_+ component must be re-expressed in terms of the $|\psi_S\rangle$ and $|\psi_L\rangle$ states, which are states which exhibit purely exponential decay,

$$|K_+\rangle=N^{-1}(\cos\theta|\psi_S\rangle+\sin\theta|\psi_L\rangle). \quad (2)$$

The fractional rate of decays into $CP=+1$ modes after a proper time t, from a beam which consists initially of pure K^0 or $\bar{K}^0$, is

$$W(t)=\tfrac{1}{2}N^{-2}\{\gamma_1|\cos\theta|^2e^{-\gamma_1t}+i[\beta\Delta\sin\theta(\cos\theta)^*e^{-\Delta t}-\text{c.c.}]+\gamma_L|\sin\theta|^2e^{-\gamma_Lt}\}, \quad (3)$$

with

$$\beta=\tanh2\chi;\quad \Delta=\tfrac{1}{2}(\gamma_1+\gamma_L)-i(m_1-m_L),$$

and where m_1, γ_1 and m_L, γ_L are the masses and widths of the states $|\psi_S\rangle$ and $|\psi_L\rangle$, respectively. We identify γ_1^{-1} with the lifetime of the short-lived mode, and assume that the lifetime γ_L^{-1} is comparable to the lifetime, γ_2^{-1}, of the long-lived K_2^0 component which, in these theories, decays exclusively into $CP=-1$ channels. The LLD effect then represents not the $\pi^+\pi^-$ decay of K_2^0, but instead the decay of an admixture of long-lived $|\psi_L\rangle$ which is necessarily present in a neutral-kaon beam by virtue of interactions which mix the $|K_+\rangle$ and $|S\rangle$ particle states. The oscillations due to the middle term in Eq. (3) will be observable in practice only if $|m_1-m_L|$ is comparable to $(\gamma_1+\gamma_L)$.

(2) Experiments which measure the branching ratios[12] of the short-lived K_1^0 mode of K^0 decay verify that half of K^0-production events[13] lead to K_1^0 decays, to an accuracy of a few percent. Since $\int_0^\infty W_+(t)dt=\frac{1}{2}$, the fraction of decays into $CP=+1$ modes at long times can be at most a few percent. According to Eq. (3), this fraction is given by

$$\int_{\gamma_1t\sim5}^\infty W_+(t)dt\approx\tfrac{1}{2}N^{-2}|\sin\theta|^2=\tfrac{1}{2}\cosh2\chi[\sin^2\varphi+\sinh^2\chi].$$

We therefore conclude that $|\theta|\ll1$; i.e., the $|\psi_S\rangle$ and $|\psi_L\rangle$ states must contain only relatively small admixtures of $|S\rangle$ and $|K_+\rangle$, respectively.

(3) The ratio R measured in the LLD effect must be interpreted as

$$R=\frac{\rho N^{-2}\{|\sin\theta|^2+|\xi\cos\theta|^2\}\gamma_Le^{-\gamma_Lt}}{(\rho_c\gamma_2e^{-\gamma_2t})}, \quad (4)$$

where we have assumed that $|S\rangle$ particles are produced incoherently, with an amplitude $\xi/\sqrt{2}$ relative to that for the production of K^0 mesons, in the target in which the kaon beam originates. ρ is the branching ratio for $\psi_L\to\pi^++\pi^-$, and ρ_c is the known branching ratio for $K_2^0\to$ charged decay modes. From the temporal variation of the events observed in the LLD effect, one knows that γ_L cannot be appreciably greater than γ_2. Hence, if we disregard the variation due to the exponential factors in Eq. (4) (since the events are observed at proper times less than or equal to $\frac{1}{2}\gamma_2^{-1}$), the approximate equality of R measured in different experiments implies the approximate constancy of the factor in curly brackets in Eq. (4). Since θ is a parameter independent of the production mechanism, this requires that $|\xi\cos\theta|$ must be appreciably smaller than $|\sin\theta|$ (unless the complex parameter ξ retains the same value under the widely different conditions of the experiments reported[14]). We have already seen that $|\theta|\ll1$. Thus,

$$|\xi|<|\theta|\ll1.$$

Therefore, S particles, if directly produced at all, are produced at a rate much lower than K^0 mesons.

(4) Thus, everything we know about the hypothetical S particles suggests that they have relatively weak interaction with matter (of the kind usually available in the laboratory[6])! If, therefore, we assume that total cross sections for the interaction of S particles with matter are smaller than K-meson cross sections by an order of magnitude or more,[15] we are in a position to propose a simple test for the particle-mixture theories.

At times long compared to γ_1^{-1}, a neutral K-meson beam consists mainly of K_2^0 and, in the particle-mixture theories, a small fraction of the state $|\psi_L\rangle$. If the LLD effect were indeed due to $\pi^+\pi^-$ decays of the K_2^0, the interposition of a thick absorber (of a few K^0 interaction lengths) upstream[16] from the LLD detector should lead to a significant reduction in the rate of LLD events. On the other hand, if the explanation of the LLD effect lies in a CP-conserving particle-mixture theory, the introduction of such an absorber should have very little effect on the rate of LLD events. In the particle-mixture theories, the LLD events arise only from the decay of $|\psi_L\rangle$, and we have seen that $|\psi_L\rangle$ can contain only a small admixture of $|K_+\rangle$. Consequently, if we assume that S-particle cross sections are much smaller than K cross sections, the $|\psi_L\rangle$ beam would be attenuated much less than the K_2^0 beam. If we make the simplifying assumption that the K_+ component of $|\psi_L\rangle$ is completely absorbed, while the amplitude of the S component is reduced by a factor λ, the residual rate of LLD events is expected to be $|\lambda\cos\theta|^2 \approx |\lambda|^2$ times the original rate (without absorber), a conclusion which is quite different from the previous case if, as we expect, $|\lambda|^2$ is not much less than unity.

It is perhaps of interest to remark that this experiment bears the same relation to the particle-mixture theories as the Pais-Piccioni experiment[17] did to the Gell-Mann–Pais theory.[9] We believe that it provides a more direct and clear-cut test of particle-mixture theories than the tests proposed in references 5-7.

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*Permanent address: University of Michigan, Ann Arbor, Michigan.

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