Further experiments are in progress, as is the preparation of a more complete report.

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Three-Pion Decay Modes of Neutral K Mesons

A. Pais, *Institute for Advanced Study, Princeton, New Jersey*

AND

S. B. Treiman, *Palmer Physical Laboratory, Princeton University, Princeton, New Jersey*

(Received April 18, 1957)

It is the purpose of this note to point out certain effects which obtain in neutral K-meson decay into pions if it is true that invariance under CP and T,[1–3] rather than under C, P, and T separately, is valid for all weak interactions (C=charge conjugation, P=space inversion, T=time reversal).

The effects concern not so much the 2π- as the 3π-decay mode. Let us assume that K^0 (and thus $\bar{K}^0$) has zero spin. The $(\pi^+\pi^-)$ and $(\pi^0\pi^0)$ decay states both are eigenstates of CP, corresponding to eigenvalue $+1$. We then characterize the K_1^0 particle by the eigenvalue $+1$ of the operator CP, which is now supposed to yield good quantum numbers.[4,5] The K_2^0 particle corresponds to $CP=-1$ and hence cannot decay into two pions. Thus, in regard to the $(\pi\pi)$ mode the situation is very much the same[2] as initially suggested.[6] The neutrino decay modes can also be separated into the $CP=+1$ and -1 channels.

The question now is what one can say about the 3π decays, which are competitive modes when we have one K-particle quartet (i.e., $\tau\equiv\theta$), as parity nonconservation suggests. Three-pion decay would be expected to occur for both the short-lived K_1^0 and the longer-lived K_2^0 particles. However, the 3π branching ratio in K_1^0 decay is likely to be extremely small: for a 3π system with angular momentum zero to have $CP=+1$, the lowest orbital state involved is characterized by $(l,L)=(1,1)$, in the notation of Dalitz.[7] This implies first of all that K_1^0 cannot have a $3\pi^0$ mode, for which $l=L$ must be even; and the (π^+,π^-,π^0) mode will be depressed by the centrifugal barrier and may reasonably be expected to have a frequency not greater than $\sim 10^{-5}$ relative to the 2π mode.

On the other hand, the 3π modes should be relatively much more important in K_2^0 decay. Here we have $CP=-1$ and thus the lowest admissible orbital state is characterized by $(l,L)=(0,0)$. Thus the K_2^0 should be able to decay according to both

$$K_2^0\rightarrow\pi^++\pi^-+\pi^0, \qquad \text{(A)}$$

$$K_2^0\rightarrow 3\pi^0, \qquad \text{(B)}$$

and these modes need have no centrifugal barrier inhibitions, in contrast to K_1^0 decay.

Thus a remarkable reversal takes place when we compare the present situation with the one which would hold if parity conservation were valid ($\tau\neq\theta$).[8] In that case the short-lived τ_1^0 would undergo 3π decay into the state (0,0)—more generally, $l=L$ even; and the longer-lived τ_2^0 would decay into the state (1,1)—more generally, $l=L$ odd. In the present case, the (1,1) state is associated with the shorter-lived K_1^0 but has extremely small branching ratio.

Inasmuch as the same 3π orbital states are available in K^+ and K_2^0 decay, namely (0,0), (2,2), $\cdots$, it seems reasonable to expect that the absolute rates of 3π decay for K^+ and K_2^0 should be of the same order of magnitude. If this is the case the partial lifetime for 3π decay of the K_2^0 would be $\sim 10^{-7}$ sec.

Insofar as the lowest orbital state predominates, we deal with 3π states which are spatially totally symmetric, both for K^+ and K_2^0. Such states can have isotopic spin $I=1$ or 3 only. The experimental branching ratio of the τ^+ to the $\tau^{+\prime}$ modes indicates that the $I=1$ state strongly predominates for K^+ decay.[9] If this is also the case for the K_2^0, then the ratio of (A) to (B) should be $\frac{2}{3}$. (If $I=3$ predominates this ratio should be $\frac{3}{2}$.)

A careful determination of the relative rates for 3π decay of K^+ and K_2^0 would provide another test of the much-discussed rule[10] (the "$\Delta I=\frac{1}{2}$" rule) that weak decay interactions transform in isotopic spin space as tensors of rank $\frac{1}{2}$. In the present case this rule would imply that the rates are identical.

The observed branching ratio $(K^+\rightarrow 2\pi^++\pi^-)/(K^+\rightarrow\pi^++2\pi^0)$ appears to be in agreement with this rule, as already mentioned. But the comparison of 3π rates for K^+ and K_2^0 would constitute a more severe test. It may be noted that present evidence[11] on the branching ratio $(\Lambda^0\rightarrow\pi^0+n)/(\Lambda^0\rightarrow\pi^-+p)$ also appears to accord with the $\Delta I=\frac{1}{2}$ rule, but the evidence[12] in $\Sigma^\pm$ decay seems to contradict the rule, as do recent results on the branching ratio $(K^0\rightarrow 2\pi^0)/(K^0\rightarrow\pi^++\pi^-)$. In the latter case the $\Delta I=\frac{1}{2}$ rule predicts the ratio $\frac{1}{2}$, whereas the experimental value[11] is interpreted to be $\lesssim\frac{1}{4}$. In fact, this last experimental result implies[13] that there are appreciable contributions from interactions which transform as $\Delta I=\frac{3}{2}$ and $\frac{5}{2}$ as well as $\frac{1}{2}$.

In τ and Λ^0 decays, considerably less kinetic energy is liberated than is the case for θ modes and $\Sigma^\pm$ decays. Whereas in the latter cases the $\Delta I=\frac{1}{2}$ rule does not work, it is perhaps significant that this rule well approximates the observed ratios in the former cases (of course, the just-mentioned 3π-decay ratio for K^+ as compared to K_2^0 remains to be studied experimentally). This would seem to indicate that, in a more fully developed dynamics of these decay processes, the isotopic transformation properties of the weak-decay couplings must involve energy-momentum-dependent parameters.

If this is indeed the case, then nonmesonic decay of hyperon fragments, with its characteristic high-energy release, need not necessarily be expected to follow closely the $\Delta I=\frac{1}{2}$ rule,[14] even though this rule seems to hold for free Λ^0 decay.

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Pion-Nucleon Interactions*

S. J. Lindenbaum and R. M. Sternheimer
Brookhaven National Laboratory, Upton, New York
(Received March 12, 1957)

FIGURE 1 shows the behavior of the pion-nucleon total cross sections[1] as a function of pion energy, when charge independence is assumed and the cross sections are separated into isotopic spin (T) states of $\frac{1}{2}$ and $\frac{3}{2}$. The well-known peak in the $\frac{3}{2}$ state at a pion kinetic energy of about 180 Mev appears to be satisfactorily explained by a p-wave resonance in the state of isotopic spin (T) and angular momentum (J) equal to $\frac{3}{2}$. The low value of the experimental limits on the $T=\frac{1}{2}$ cross section below 200 Mev and the peak in this cross section at about 0.9 Bev have not been satisfactorily explained to date although many attempts have been made, including notably the pion-pion interaction scheme of Dyson,[2] Takeda,[3] and Piccioni.[1]

A major difficulty of the Dyson-Takeda scheme is the expected effect of the momentum distribution of the pions in the nucleon cloud which requires too large[1] (± 1 Bev/c) a smearing out of even a sharp resonance effect. Furthermore, in a study of the inelastic pion production Walker *et al.*[4] conclude that the experimental evidence does not support this model.

In a previous publication[5] we have found it possible to explain the major features of pion production in nucleon-nucleon collisions in the 0.8- to 3.0-Bev incident energy range by assuming that all inelastic reactions proceed via excitation of one or both nucleons to an isobaric nucleon level with $T=J=\frac{3}{2}$.

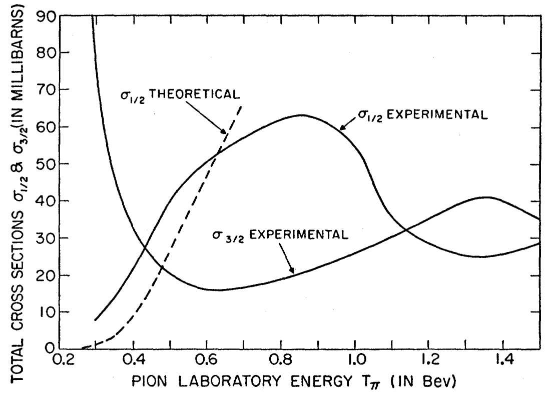

FIG. 1. Total cross sections $\sigma_{\frac{1}{2}}$ and $\sigma_{\frac{3}{2}}$ for the pion-nucleon interaction in the $T=\frac{1}{2}$ and $T=\frac{3}{2}$ states. The solid curves are based on the experimental values (reference 1). The dashed curve gives the theoretical values of $\sigma_{\frac{1}{2}}$ near threshold obtained from Eq. (1) with a suitable choice of $A_{\frac{1}{2}}$.

During this work it occurred to us that perhaps the behavior of the $T=\frac{1}{2}$ cross section could be explained by assuming that all pion-nucleon interactions of pion kinetic energy less than 1.5 Bev proceed via excitation of this one state. Hence one would not find any $T=\frac{1}{2}$ cross section until a threshold energy ($\gtrsim 200$ Mev) is reached which is sufficient to form an isobar of $T=J=\frac{3}{2}$ with a separate recoil pion. The separate recoil pion allows the total system of an isobar with $T=\frac{3}{2}$ and a separate recoil pion with $T=1$ to have a total $T=\frac{1}{2}$.

The variation of the cross section $\sigma_{\frac{1}{2}}(T_\pi)$ near threshold as a function of incident pion energy T_π was assumed in analogy to our previous treatment for nucleon-nucleon collisions to be given by

$$\sigma_{\frac{1}{2}}(T_\pi)=A_{\frac{1}{2}}\int F(T_\pi,m_I)\sigma_{\frac{3}{2}}(m_I)dm_I, \qquad (1)$$

where m_I is the total mass in the isobar rest system, $F(T_\pi,m_I)$ is the two-body phase space factor for an isobar of mass m_I and the recoil pion, $\sigma_{\frac{3}{2}}(m_I)$ is the total π^+-p scattering cross section, and $A_{\frac{1}{2}}$ is an arbitrary constant. It has been assumed that the ratio of the elastic and inelastic cross sections is independent of energy.

A plot of Eq. (1) is shown in Fig. 1 with $A_{\frac{1}{2}}$ adjusted for a reasonable fit. As one can see, the rise of the $T=\frac{1}{2}$ cross section from threshold to the region near the peak is generally similar to the prediction based on Eq. (1). Of course Eq. (1), which is the expression predicted near threshold, does not level off or saturate with increasing energy as one would expect a physical process of this type to do in general because of the fact that $\lambda\!\!\!^{-} < R$, where R is the range of interaction. Furthermore the process may involve resonance of certain waves which would lead to a peak and a decrease thereafter.

In the present crude model one can just expect to explain the threshold and the general behavior of the