Photoproduction of K Mesons in Hydrogen*

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We have used the 1080-Mev bremsstrahlung beam from the Cornell electron synchrotron to measure the differential cross section for production of K^+ mesons at 155° center-of-mass angle by 1-Bev photons. The experimental arrangement is shown in Fig. 1. Positively charged particles in the momentum interval (175±10) Mev/c are bent through 90° by the double focusing ($n=\frac{1}{2}$) magnet, M. A particle emerging from the magnet is identified as a K particle if it makes sufficiently large pulses in counters A, B, C, and D together with a count in the side counter E within 5×10^{-8} sec of the prompt $A\ B\ C\ D$ coincidences. Counter E is a cylindrical shell of Scintillon whose o.d.=8 in., i.d.=4 in., and length=6 in. Discrimination against π mesons, whose flux is about 5×10^3 that of the K's, is accomplished by demanding large pulses in A, B, and C. π mesons of momentum 175 Mev/c give pulses about $\frac{1}{5}$ that of K's of the same momentum. Protons of this momentum stop in counter B. The gains on counters A, B, and C are adjusted by observing the pulse-height distribution produced in each of the counters by π mesons and protons. Protons are observed in B, C, and D by removing the necessary counters. This pulse-height requirement, together with the momentum selection is, in principle, sufficient to select K mesons. However, with counters A, B, and C set to eliminate π mesons, the coincidence rate in A, B, C, and D is still 50× the K-meson rate. These coincidences, which are less than 1% of the π mesons traversing the magnet, probably arise from π mesons and protons which traverse the magnet in some unpredicted way, i.e., scattering from the pole faces, and so do not have the predicted pulse heights in counters $A\ B\ C$. To eliminate this background we require counter E to detect at least one of the decay particles of the K mesons. With this additional requirement, the background is less than 10% of the K rate.

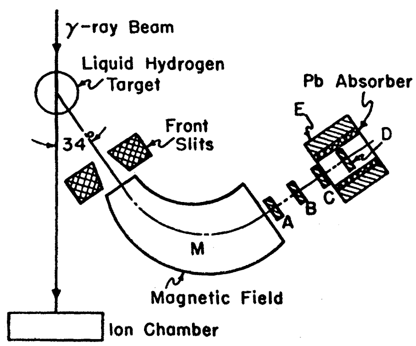

FIG. 1. Schematic arrangement of the apparatus (not to scale).

The $D\ E$ coincidences are made with two different resolving times—5×10^{-8} sec and 5×10^{-7} sec. The fast resolving time is chosen to be long compared with the K lifetime ($\tau_K=1.24\times10^{-8}$ sec) so that not many K's will be missed; and short compared to the μ-e lifetime ($\tau_\mu=2.22\times10^{-6}$ sec) so that the efficiency for μ-e detection is poor. The slow coincidences ($\tau_{\text{resolving}}=5\times10^{-7}$ sec) are taken to obtain information about the accidental rate and the μ-e contamination. It is possible for a slow π meson to stop in counter D, decay into a μ meson which remains in counter D, and then have the electron from the μ-e decay register in counter E. This would, of course, satisfy the criteria for a K meson. The ratio of accidental counts and the μ-e background in the fast and slow channels should both be in the ratio of the two resolving times. By making both the slow and fast coincidences we could determine that both of the foregoing background sources were negligible.

The reaction being observed is presumably $\gamma+p\rightarrow K^++\Lambda^0$. The other known reactions by which K's could be produced are ruled out by the kinematics and the peak beam energy. The observations were made at a laboratory angle (between the K meson and the γ-ray beam) of 34°. The K's were produced at a center-of-mass angle of (155±10)° by γ rays of energy (990±30) Mev. The target was liquid hydrogen. Let $k_{\max}$ be the upper end of the bremsstrahlung spectrum. Observations were made under the following conditions: (a) $k_{\max}=1080$ Mev, target full; (b) $k_{\max}=1080$ Mev, target empty; (c) $k_{\max}=900$ Mev, target full. The last run was taken as a measure of the non-K-particle contamination since the threshold for the reaction $\gamma+p\rightarrow K^++\Lambda^0$ is 910 Mev. The results are shown in Table I.

TABLE I. Production and background counts for the reaction $\gamma+p\rightarrow K^++\Lambda^0$ at a laboratory angle of 34°.

$k_{\max}$	Target	Integrated beam	No. of counts
1080	Full	13.8×10^{15} Mev	27
1080	Empty	4.87×10^{15} Mev	1
900	Full	5.83×10^{15} Mev	1

The single count in the $k_{\max}=900$ Mev run is consistent with the expected accidental rate. The expected accidental rate at the lower beam energy is about five times as great as that at the higher energy because of the shorter time spread of the beam.

The corrections for decay in flight and efficiency of counter E detecting one of the decay products are made assuming a lifetime for all K's of 1.24×10^{-8} sec and the usual distribution of decay modes.[1] There is at present no information about the distribution from K's produced by γ rays. After the appropriate corrections are made, the cross section measured is

$$\frac{d\sigma}{d\Omega}(\theta_{\text{c.m.}}=155°)=(0.89\pm0.21)\times10^{-31}\ \text{cm}^2/\text{sterad}$$

for a γ ray of energy (990 ± 30) Mev. The error is statistical. We estimate systematic errors to be about 30% primarily arising from uncertainty about the bremsstrahlung spectrum close to the upper end. The beam integration was carried out using a total absorption ion chamber.[2]

Measurements of the photoproduction of K mesons by 1-Bev γ rays have been reported previously by Donoho and Walker at the California Institute of Technology.[3] Their measurements together with ours are plotted in Fig. 2. The curves drawn are from calculations by Fujii and Marshak.[4] The curve labeled S' is calculated for a scalar K meson and the one labeled PS' is for a pseudoscalar K meson. An anomalous magnetic moment of 1.793 nm is taken for the proton and 1.212 nm for the Λ^0 in both cases. The form of the curve for scalar K mesons is typical of photoelectric production (retarded $\sin^2\theta$) and seems to be rather insensitive to the detailed assumptions of the theory. The PS' curve depends critically on the assumption of the theory, particularly the sign and magnitude of the anomalous moment of the Λ^0. The absolute values of the cross sections determine the coupling constant $G_{NK\Lambda}{}^2/4\pi$ which is otherwise arbitrary in the theory. The results are consistent with a scalar K meson with a coupling constant $G_{NK\Lambda}{}^2/4\pi=3\pm1$. This is a rather large coupling constant. It should be emphasized that the above statement is meant to indicate a trend and should not be taken as strong evidence against pseudoscalar K mesons.[5] Because of the sensitivity of the calculations to the precise choice of anomalous moment, the present experimental data are insufficient to allow a reliable choice between the scalar and pseudoscalar theories to be made. This decision must await more complete information about the angular distribution, particularly at forward angles.

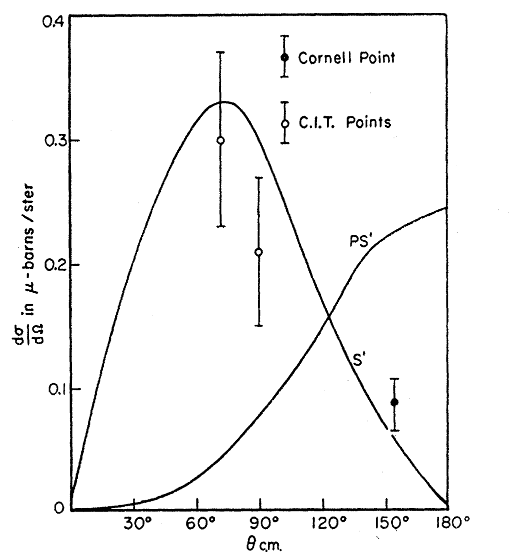

FIG. 2. Plot of the measured differential cross sections from this experiment and that of Donoho and Walker. The curves labeled PS' and S' are taken from the calculations of Fujii and Marshak. The assumptions under which the calculations were made are discussed in the text.

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[2] R. R. Wilson, Nuclear Instr. **1**, 101 (1957).
[3] P. L. Donoho and R. L. Walker, Phys. Rev. **107**, 1198 (1957).
[4] A. Fujii and R. Marshak (private communication). See also A. Fujii and R. Marshak, Phys. Rev. **107**, 570 (1957), and M. Kawaguchi and M. J. Moravcsik, Phys. Rev. **107**, 563 (1957).
[5] In fact, the K meson could be a parity doublet and have both scalar and pseudoscalar components.

Time Reversal in Nuclear Interactions*

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THE recent demonstration[1] that parity conservation, charge-conjugation invariance, and perhaps time-reversal (TR) invariance do not hold in weak interactions should cause physicists to re-examine the foundations of their beliefs that strong interactions are invariant with respect to these symmetries. Lee and Yang[2] summarize some of the older evidence for believing in the parity conservation of strong interactions; their conclusions have been considerably strengthened by recent experiments,[3] which indicate that states with opposite parity are not mixed by nuclear forces with amplitudes as large as 10^{-3} to 10^{-4}.

We have accepted the evidence for parity conservation in strong interactions as amply convincing, and have examined in some detail TR invariance in nuclear interactions. One conclusion of this study is that the present data do not exclude the possibility that nuclear forces which are odd with respect to TR may be present with a strength of as much as 10–20% of the total force. This figure is obtained from angular correlation studies[4] of successive radiations in Hg^{198}, as well as from the reactions[5–7] $p+H^3\rightleftarrows n+He^3$, $p+He^3\rightleftarrows\gamma+He^4$, and $p+Li^7\rightleftarrows d+Li^6$. In angular correlations, if one of the radiations in a cascade consists of a superposition of two angular momenta, then TR invariance predicts[8] an interference term with a phase of 0° or 180°. The most sensitive determination of the phase that we have found is in the angular correlation of the[4] $2(E2+M1)2(E2)0$ cascade in Hg^{198} in which the phase is found to be larger than 159°. In nuclear reactions, the lack of TR invariance would be manifested by the nonreality of certain matrix elements and by the consequent lack of the reciprocity property of the S matrix,