have corresponded to a leptonic decay probability of $1/(0.75\times 84)=1.6\%$. Using the Σ^- lifetime, $\tau_\Sigma=1.7\times 10^{-10}$ sec, this corresponds to a combined leptonic decay rate of the order of $9.4\times 10^{+7}$ sec^{-1} or less.

These results are tabulated in Table I. Both in the case of Λ^0 and Σ^0 decay the experiment should have been sufficiently sensitive to see leptonic decays with the probability predicted in the universal V-A theory. In each case 5–6 events should have been observed, but none were. This, it seems to us, makes the model untenable in this form for these hyperons. It need hardly be added that this is no way detracts from its success in β and μ decay. However, the simple extension of coupling (3) to the Λ^0 and Σ^- is very unlikely in view of these results.

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Photoproduction of K^+ Mesons in Hydrogen*

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K^+ mesons produced in a liquid hydrogen target bombarded by the 1100-Mev bremsstrahlung of the California Institute of Technology synchrotron have been observed. It has been found that the K^+ mesons are produced in association with Λ^0 hyperons, in accordance with the law of associated production of strange particles. The K^+ mesons were momentum-analyzed in a magnetic spectrometer and identified by their energy loss in three scintillation counters, the very large background due to pions and protons being virtually eliminated by means of time-of-flight discrimination. The differential cross section for the reaction $\gamma+p\rightarrow K^++\Lambda^0$ has been measured at photon energies of 960 Mev, 1000 Mev, and 1060 Mev at various K^+-meson laboratory angles between 15 degrees and 45 degrees. This cross section shows little variation with photon energy between 960 Mev and 1060 Mev or with center-of-momentum angle over the range investigated.

1. INTRODUCTION

WHEN the electron synchrotron at the California Institute of Technology began operation at an energy of 1100 Mev, a search was begun for K^+ mesons produced in photon-nucleon collisions. Because of the lack of a source of photons of sufficiently high energy, the photoproduction of the strange particles had not been previously observed. It was, therefore, desired to ascertain whether K^+ mesons are produced at all in photonuclear reactions and, if so, whether they are produced according to the law of associated production of strange particles.[1]

Three reactions involving K^+ mesons are energetically possible with photons of energies less than 1100 Mev:

$$\gamma+p\rightarrow K^++\Lambda^0 \text{ (threshold 910 Mev)}; \quad (1)$$

$$\gamma+p\rightarrow K^++\Sigma^0 \text{ (threshold 1040 Mev)}; \quad (2)$$

$$\gamma+p\rightarrow K^++n \text{ (threshold 630 Mev)}. \quad (3)$$

The first two reactions conserve strangeness and were expected to occur, whereas the third should be very much weaker according to the theories of strange particles.[1]

The three reactions above can be distinguished by differences in their kinematic relations arising from the differences in the masses of Λ^0, Σ^0, and n. Thus K^+ mesons produced at a given angle and a given energy must be produced by photons of different energy for the three reactions. This is illustrated quantitatively in Fig. 1. No information has been obtained in the present experiment about the production of K^+ with Σ^0 since photons of energies greater than the bremsstrahlung upper limit would have been required to produce K^+ mesons from reaction (2) at the angles and energies observed. Furthermore, by lowering the synchrotron energy below that required for reaction (1), it was found as expected that less than 5% of the K^+ mesons can come from reaction (3). Thus, the K^+ particles observed in the present experiment are produced with Λ^0 in reaction (1), and the data are reduced to differential cross sections for this reaction.

Preliminary results of the present experiment have been reported previously.[2] The cross sections presented here differ somewhat from the earlier ones not only because additional data have been obtained, but also because of changes in the assumed bremsstrahlung spectrum based on pair spectrometer measurements,[3] and because of a small change in the beam monitor calibration.[4]

K^+-particle photoproduction is also being investigated at Cornell. Silverman, Wilson, and Woodward[5]

* This work was supported in part by the U. S. Atomic Energy Commission.
† Now at Bell Telephone Laboratories, Inc., Murray Hill, New Jersey.
[1] M. Gell-Mann, Nuovo cimento 4, Suppl. 2, 848 (1956).

[2] P. L. Donoho and R. L. Walker, Phys. Rev. **107**, 1198 (1957).
[3] Donoho, Emery, and Walker (unpublished).
[4] R. Gomez, internal report (unpublished).
[5] Silverman, Wilson, and Woodward, Phys. Rev. **108**, 501 (1957).

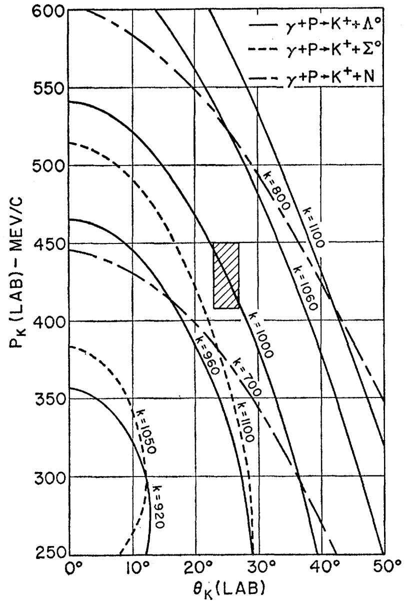

FIG. 1. A portion of the kinematic relations for the three reactions discussed in the Introduction, illustrating the method of distinguishing between these reactions. k=photon energy in Mev. The shaded rectangle shows the region of momentum and angle accepted by the spectrometer for one of the points measured at 1000 Mev.

have obtained a value of the cross section at $K=990$ Mev and $\theta_{\text{c.m.}}=155°$ of $\sigma(\theta)=(0.89\pm0.21)\times10^{-31}$ cm²/sterad. This is lower than our values at angles $\theta_{\text{c.m.}}=45°$ to 90°, which are near $\sigma(\theta)=1.5\times10^{-31}$ cm²/sterad. More recent data from Cornell[6] at angles 45° and 70° c.m. are also slightly lower than our values in the same region. Further work at Caltech[7] at 30° and 70° c.m. with 1000-Mev photons is in good agreement with, though slightly lower than, the data reported here.

Other early experiments in which photoproduced K^+ mesons were observed were reported by Clegg, Ernstene, and Tollestrup,[8] and by Peterson, Roos, and Terman.[9]

2. EXPERIMENTAL TECHNIQUE

In this experiment, the differential cross section for reaction (1) was measured at various center-of-momentum angles and photon energies by counting K^+ mesons at the appropriate laboratory angles and energies. The difficulties in the experiment arise from the small number of K particles produced and the relatively large numbers of pions and protons. Thus the counting rate is low, and considerable care is necessary in the identification of the K^+ particles.

The method employed in this experiment for the identification of the K^+ particles was to combine a momentum measurement by a magnetic spectrometer, a time-of-flight velocity selection, and measurements of the energy loss of the particles in each of three scintillation counters located near the focus of the spectrometer.

The apparatus is shown schematically in Fig. 2. The uniform-field magnet and counter C_2 form a single-focusing spectrometer capable of measuring particles of momenta up to 600 Mev/c. The solid angle of the aperture as defined by lead absorbers is 0.0075 steradian. The momentum interval accepted, $\Delta p/P=0.098$, is determined by the width of counter C_2, 12.1 cm. The counters C_1 and C_3 as well as C_2 are used to provide pulse height data for the energy loss measurements. Some "defocusing" of the particles in the direction normal to the plane of Fig. 2 occurs in the fringe field of the magnet so that the counters must be rather long (28 cm) in this direction. The light from each of these counters was collected by two photomultipliers, one at each end, and the signals added in order to improve the pulse height resolution.

Counters C_0 and C_2 which are 380 cm apart are used with a fast coincidence circuit to provide the time-of-flight velocity selection. This will be described in detail below.

The absorbers A_2 and A_3 were used to stop protons having the spectrometer momentum. Absorber A_0 was used to reduce the singles counting rate of C_0 to an acceptable level ($<5\times10^6$ per second instantaneous rate). Since much of this counting rate comes from very low-energy electrons emerging from the target, $\frac{1}{2}$ inch of polyethylene was usually sufficient. However, for one measurement at 15° a 3-inch carbon absorber was used for A_0.

The entire system of magnet and counters is mounted on a rotating carriage with a pivot on the axis of the liquid hydrogen target so that the angle of observation can be changed easily.

The liquid hydrogen of the target is contained in a cylindrical cup 3 inches in diameter, with a 0.003-inch Mylar wall. This is surrounded by radiation shields and by a 0.024-inch Mylar external vacuum window. However, no particles produced in these outer shields by the beam were detected except at the most forward angle, since the portions of the shields through which the beam passes are excluded from view by the slit

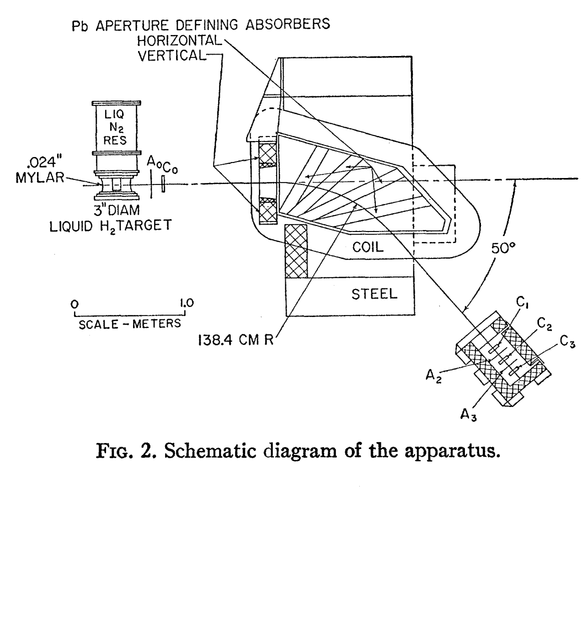

FIG. 2. Schematic diagram of the apparatus.

[6] McDaniel, Cortellesa, Silverman, and Wilson, Bull. Am. Phys. Soc. Ser. II, 3, 24 (1958). Also private communication.

[7] Brody, Wetherell, and Walker, Phys. Rev. 110, 1213 (1958). The results reported in that paper are too high, however, because of a recently discovered systematic error.

[8] Clegg, Ernstene, and Tollestrup, Phys. Rev. 107, 1200 (1957).

[9] Peterson, Roos, and Terman, Bull. Am. Phys. Soc. Ser. II, 2, 235 (1957).

system consisting of counter C_0 and the magnet aperture.

The bremsstrahlung beam is collimated to a rectangular cross section 5.1×6.3 cm^2 at the hydrogen target. The synchrotron produces one beam pulse per second, and by tailoring the rf amplitude this pulse is spread out fairly uniformly in time for about 20 milliseconds. During this time the magnetic field of the synchrotron is held at a constant value so that the bremsstrahlung has a well-defined end-point energy. The bremsstrahlung spectrum has been measured by means of a pair spectrometer[3] and found to be much more similar to a thin-target spectrum than to the spectrum calculated for a radiator of thickness 0.2 radiation length, the geometrical thickness of our radiator. (Presumably the electrons barely graze the edge of the radiator, and do not pass through the full thickness.) Thus the spectrum assumed in calculating cross sections was essentially the thin-target one. The absolute calibration of our beam monitor is based on a comparison[4] with a "quantameter" designed by Wilson,[10] using his value for its absolute sensitivity (4.82×10^{18} Mev per coulomb for a gas mixture of 760-mm argon and 40 mm of CO_2 at 20°C).

3. TIME-OF-FLIGHT SELECTION

As described above, a velocity selection was made by requiring a fast coincidence between counter C_2 and a suitably delayed pulse from counter C_0. For the flight path used, the difference in flight times for pions and for K mesons varied from 4.2 mμsec at 520 Mev/c to 9.3 mμsec at 320 Mev/c. The coincidence resolving time of about 4 millimicroseconds full width at half-maximum was a compromise between a resolving time short enough to reject all undesired events and one long enough to give 100% efficiency for counting K particles. A compromise is necessary because at the highest momentum investigated, 520 Mev/c, the mean difference in flight times for pions and K particles is only 4.2 millimicroseconds, which is not long compared to the spread in times of arrival of the pulses from K particles themselves. The latter spread results from several causes. First, different paths through the spectrometer have different lengths amounting to 1.25 mμsec for particles of velocity c, but up to 2.5 mμsec for the slowest K particles investigated. Second, the width of the momentum interval accepted results in a range of velocities corresponding to as much as 2 mμsec difference in flight times. Third, the length of counter C_2, 28 cm, means that light originating from particles hitting the counter at different points takes different times to reach the photomultiplier. (Signals from only one photomultiplier were used for the fast coincidence circuit.) Finally, there are some variations in transit times for electrons in the photomultipliers (RCA 6810).

The result of the above compromise was a time-of-flight requirement which rejected about 98% of the pions and counted the desired events with an efficiency of 85 ± 1%. The latter figure, which enters into the cross sections, of course, was measured for pions and protons and since the result was the same in both cases, the same figure was assumed for K particles. The measurement of this efficiency was made by comparing the counting rate when a fast C_0+C_2 coincidence was required together with a slow (0.1-microsecond) coincidence with C_1 and C_3, to the counting rate when only a slow coincidence $C_1+C_2+C_3$ was required. When pions were being counted, absorbers A_2 and A_3 stopped protons, and when protons were being counted, these absorbers were removed and the pions were biased out on the basis of pulse height. The efficiency of the fast coincidence circuit as measured by the above ratio is shown in Fig. 3 as a function of the delay introduced for the pulse from C_0. This figure also shows the time resolution curve of the system, and is used to find the proper delay for counting K particles.

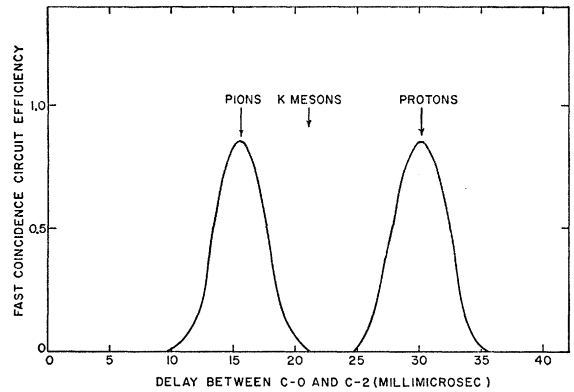

FIG. 3. Efficiency of the fast time-of-flight coincidence system as a function of the delay in the signal from counter C_0. This was measured for both pions and protons in the manner explained in the text.

The usefulness of the time-of-flight requirement is indicated by the improvement it makes in the relative numbers of counts due to K mesons and other particles. In a typical arrangement, the ratios of protons to pions to K^+ particles accepted by the magnetic spectrometer alone is about 2000:1000:1. By the use of absorbers A_2 and A_3 to stop protons and by the requirement of the time-of-flight coincidence, but without the introduction of any pulse-height bias against pions, the counting rate was reduced so that about one count in 10 or 20 was a K meson. With this ratio, a final identification on the basis of pulse heights in C_1, C_2, and C_3 is possible.

4. PULSE-HEIGHT ANALYSIS

In addition to the momentum and velocity selection, the K^+ particles were required to have the correct energy loss in the three scintillators C_1, C_2, and C_3. This was done by displaying the pulses from these three

[10] R. R. Wilson (to be published).

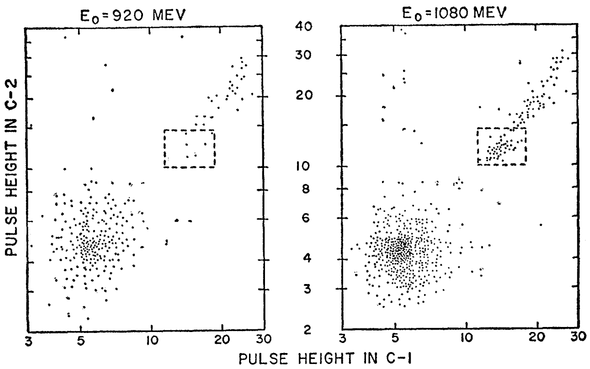

FIG. 4. Correlations in pulse height for counters C_1 and C_2 for data taken with $P_{\text{lab}}=320$ Mev/c, $\theta_{\text{lab}}=25°$, $k=960$ Mev; $E_0=920$ Mev, 3000 beam units (background); $E_0=1080$ Mev, 6000 beam units. The rectangle with dashed boundaries is the region in which K^+-meson events should appear.

counters, suitably delayed by different amounts, on an oscilloscope and photographing them individually for each event consisting of a C_0+C_2 fast coincidence in slow coincidence with C_1 and C_3. The three pulse heights for each event were then read from the film and analyzed as follows. First the single-counter spectrum for each counter was plotted, showing primarily the pion peak, since the majority of photographed events were pions. This was used as a calibration to find the mean value and the standard deviation expected for K^+-particle pulses. The standard deviations observed for pions were only slightly greater than those predicted by the theory of energy-loss fluctuations of Symon.[11] An interval of about four standard deviations centered about the expected mean for K^+ mesons was thus established for each counter. To be identified as due to a K^+ particle, all three pulse heights must lie in the specified region. Fortunately, the application of this requirement to only two counters was usually sufficient so that the third pulse height could be regarded as a consistency check.

The extent to which the pulse heights in two counters alone are sufficient to select K^+ mesons is illustrated in Figs. 4, 5, and 6, which show the correlated pulse heights from counters C_1 and C_2 for typical data obtained at momenta of 320 Mev/c, 420 Mev/c, and 520 Mev/c. The dashed rectangles bound the regions expected to contain the K^+-meson events on the basis of the single-counter spectra. The left-hand portion of each figure presents data taken with reduced synchrotron energy and represents the background, as will be explained in the following section. In each case, the K^+-meson rectangle contains a group of points which is considerably reduced in the background run. (When three counters are used, this reduction is as much as a factor of twenty.) In addition to the K-meson groups, Figs. 4, 5, and 6 show large groups of pions, as expected, and groups of points having larger pulse heights than K mesons. These latter events, we believe, represent protons of momenta higher than that defined by the spectrometer, which scatter from the pole pieces of the magnet or the lead slits in such a way as to pass through the counter system. Such scattered protons of high energy can have sufficient range to traverse absorbers A_2 and A_3, and a velocity sufficiently high to satisfy the time-of-flight selection, in which case they can also produce pulse heights not greatly different from those produced by K particles. They are thus a particularly annoying source of background.

[11] K. Symon, thesis, Harvard University, 1948 (unpublished).

5. BACKGROUND AND IDENTIFICATION OF THE REACTION BY WHICH THE K PARTICLES ARE PRODUCED

The sources of background were the following:

(1) Some pions passed by the time-of-flight system produce pulses in the K region of all three counters because of fluctuations in the energy loss. This is significant only for the high-energy K data.

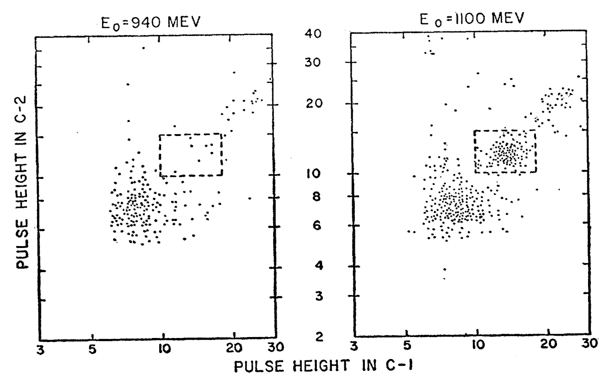

FIG. 5. Pulse-height correlations for counters C_1 and C_2 for data taken with $P_{\text{lab}}=425$ Mev/c, $\theta_{\text{lab}}=25°$, $k=1000$ Mev; $E_0=940$ Mev, 2400 beam units (background); $E_0=1100$ Mev, 5000 beam units.

(2) Some scattered protons, as described above, produce pulses in the K region in all three counters.

(3) Some K^+ mesons are produced in the Mylar walls of the hydrogen target. This is a small effect which was estimated simply on the basis of numbers of protons in the walls relative to the number in the liquid hydrogen.

(4) If one uses the measurements to obtain the cross section for producing K^+ with Λ^0 (reaction 1), then any K mesons produced with n (reaction 3) should be considered a background. As mentioned in the Introduction, this is expected to be negligible, and if it existed would be interesting in itself, of course.

Background from sources 1, 2, and 4 was measured all together by taking data with the synchrotron energy reduced below that required to give K^+ mesons from reaction (1) (i.e., produced with Λ^0) in the angular and momentum regions accefted by the spectrometer.

The numbers of pions should remain essentially unchanged and also the number of K^+ mesons produced from reaction 3 with a neutron. The number of very-high-energy protons which could scatter and be counted might be decreased when the synchrotron energy is lowered, but this effect should be small, since the energy was lowered only slightly. As a check that the background is measured correctly by this procedure, it was observed that the counting rates in the pion region of pulse heights and in the "scattered proton" region were not changed by lowering the synchrotron energy by more than might be expected from the statistical errors.

Since the counting rate of K^+ particles produced with neutrons in violation of the law of conservation of strangeness (reaction 3) would not be changed when the synchrotron energy is lowered slightly, the lowest background observed of 5% may be taken as an upper limit to the number of K^+ mesons produced with neutrons relative to the number produced with Λ^0.

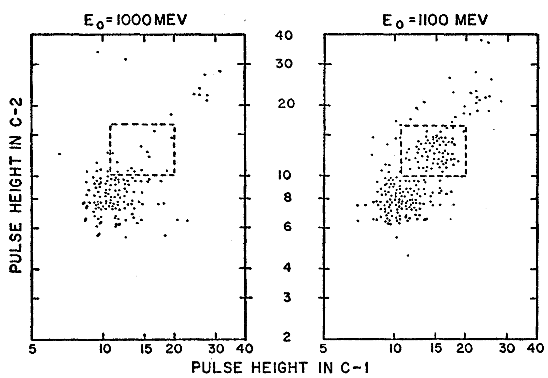

FIG. 6. Pulse-height correlations for counters C_1 and C_2 for data taken with $P_{\text{lab}}=520$ Mev/c, $\theta_{\text{lab}}=25°$, $k=1060$ Mev; $E_0=1000$ Mev, 1200 beam units (background); $E_0=1100$ Mev, 2400 beam units.

6. RESULTS

Data were obtained at the K^+ laboratory angles and momenta indicated in Fig. 7. No work was done at momenta below 320 Mev/c because the counting rate became too low due to decay in flight and dynamical factors; no work was done at momenta above about 520 Mev/c because of poor time-of-flight and pulse-height resolutions. Angles less than 15 degrees were not accessible because of the large counting rate in C_0. The points were chosen to give measurements at three c.m. angles each at 1000 Mev and 1060 Mev as well as three energies at 90° c.m.

The data obtained are presented in Table I. In this table are shown the observed counting rates in the K-meson region of pulse heights for both the high-energy runs and the background runs at reduced energy. From the net counting rate, the differential cross section for producing $K^+ + \Lambda^0$ has been calculated and is shown in the last column of the table.

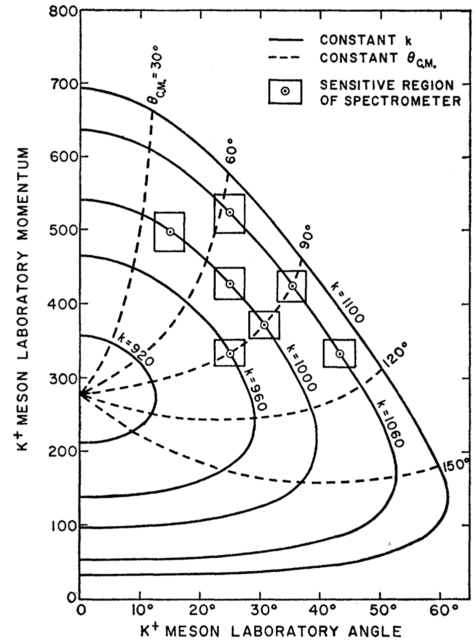

FIG. 7. Kinematic relations for the reaction $\gamma+p\rightarrow E^+ + \Lambda^0$, with rectangles showing the regions of K^+-meson momentum and angle accepted by the spectrometer for each of the points measured. k=photon energy in Mev.

In calculating cross sections, a correction for the 15% inefficiency of the time-of-flight system has been included, and a small correction for scattering and absorption in the counters and absorbers. Important here is a large correction for the decay of the K mesons before reaching the final counter. In calculating this correction, which is given for interest in Table I, a mean

TABLE I. Results: P_{lab}, θ_{lab}, and $\theta_{\text{c.m.}}$ are the laboratory momentum and angle and the center-of-momentum angle of K^+ mesons produced by photons of energy k in the reaction $\gamma+p\rightarrow K^+ + \Lambda^0$. E_0 is the synchrotron energy. Background runs are those for which $E_0<k$. $\sigma(\theta_{\text{c.m.}})$ is the differential cross section for the above reaction in the c.m. system. The counting rates are given in units of counts per 100 beam units, one unit being 1.36×10^{12} Mev total integrated bremsstrahlung energy. The decay correction is simply the probability that a K^+ meson does not decay before reaching the last counter.

P_{lab} (Mev/c)	θ_{lab}	E_0 (Mev)	k (Mev)	$\theta_{\text{c.m.}}$	Decay correction	Counting rate	$\sigma(\theta_{\text{c.m.}})$ (10^{-31} cm²/sterad)
335	25.1°	1080 920	960	90°	0.169	0.51±0.09 0.14±0.05	1.18±0.35
499	15.0°	1100 940	1000	42°	0.284	1.79±0.18 0.21±0.09	1.61±0.20
427	25.0°	1100 940	1000	72°	0.259	1.30±0.19 0.60±0.06	1.86±0.28
372	30.6°	1100 940	1000	90°	0.208	0.69±0.08 0.12±0.06	1.46±0.23
523	25.0°	1100 1000	1060	64°	0.336	2.98±0.31 0.52±0.20	2.19±0.32
422	35.6°	1100 1000	1060	90°	0.259	0.95±0.13 0.09±0.09	1.47±0.26
336	43.3°	1100 1000	1060	110°	0.169	0.24±0.06 0	1.30±0.32

life of[12] $(1.24\pm0.02)\times10^{-8}$ sec was used, and it was assumed that no K mesons which decayed would be detected. A rough estimate of the probability of counting one of the products of K-meson decays indicates that this is a very small effect.

It may be seen from Table I that over the angular and energy region investigated in this experiment, no very significant variations in the cross section were observed. In fact, all except the highest and lowest values fall within their errors at a value 1.5×10^{-31} cm^2/sterad, and these two exceptions are only about $1\frac{1}{2}$ standard deviations from this value. With this limitation, it might still be remarked that the angular distribution at 1060 Mev seems to be peaked forward, whereas that at 1000 Mev does not. However, if one compares these data with the value $\sigma(\theta)=0.89\times10^{-31}$ cm^2/sterad obtained at Cornell by Silverman, Wilson, and Woodward,[5] at 990 Mev and $\theta_{\text{c.m.}}=155°$, the angular distribution at 1000 Mev also seems to fall at backward angles.

The excitation curve at $\theta_{\text{c.m.}}=90°$ seems rather flat between 960 and 1060 Mev according to the values of Table I, although again the errors are unfortunately large. This behavior would be expected in general if the K mesons are produced in S waves near the threshold.

Several theoretical treatments of K-particle photoproduction have been given,[13] but in view of the uncertainties in the theories and the large errors in the experimental data, it would probably be premature to draw detailed conclusions about the K-hyperon interaction. A rather general conclusion from the magnitude of the cross sections has already been pointed out and used in a theory of the strange-particle interactions, by Gell-Mann.[14] This is that the K-Λ^0 coupling is perhaps weaker than the pion-nucleon one.

The measurements of K^+-meson photoproduction by the general method reported here are being continued with some improvements by Brody, Wetherell, and Walker.[7] The results obtained thus far are in good agreement with those reported here, but the errors are comparable. It would be especially desirable now to obtain more accurate data.

7. ACKNOWLEDGMENTS

We wish to thank Mr. H. M. Brody and Mr. F. P. Dixon for assisting in the performance of this experiment, and Mr. E. B. Emery for the maintenance of the liquid hydrogen target. We are indebted to the entire staff and to graduate students of the Synchrotron Laboratory for contributing to the operation and maintenance of the synchrotron.

[12] See for example L. W. Alvarez, *Proceedings of the Seventh Annual Rochester Conference on High-Energy Nuclear Physics* (Interscience Publishers, Inc., New York, 1957).

[13] M. Kawaguchi and M. Moravcsik, Phys. Rev. **107**, 563 (1957); A. Fujii and R. Marshak, Phys. Rev. **107**, 570 (1957); D. Amati and B. Vitale, Nuovo cimento **6**, 394 (1957); B. T. Feld and G. Costa, Phys. Rev. **110**, 968 (1958).

[14] M. Gell-Mann, Phys. Rev. **106**, 1296 (1957).

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Pion-Hyperon Scattering and K^--p Reactions*

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A brief survey is made of the consequences of the universal pion-baryon interaction on production of hyperons with pions. In particular, a pion-hyperon resonant scattering state similar to the $p_{\frac{3}{2}}$, $T=\frac{3}{2}$ pion-nucleon state should exist. Possible effects of this state are examined. It is found that the large low-energy K^--p cross sections cannot be associated with it. Other experiments are suggested in order to search for this state, especially K^--p reactions at higher energy and pion production in hyperon-nucleon scattering.

INTRODUCTION

IN addition to its attractive simplicity, the assumption of a pion-baryon interaction of universal strength and form[1] has led to some agreement with hyperon nucleon forces.[2] The purpose of this paper is to find a qualitative test of this assumption in hyperon production. This, it is hoped, may be of some value in suggesting experimental possibilities. It shall be assumed that the pion-baryon interaction is somewhat stronger than the K-particle interactions. In order to avoid great involvement in these unknown K interactions we shall examine here the effects of pion-hyperon scattering. In particular we shall consider the most prominent effect: the $p_{\frac{3}{2}}$ resonance in pion-hyperon scattering which is the counterpart of the $T=\frac{3}{2}$, $p_{\frac{3}{2}}$ low-energy resonance in pion-nucelon scattering. This is not to be directly observed, of course, but it should have a substantial effect on processes involving production

* Supported in part by the National Science Foundation.

[1] M. Gell-Mann, Phys. Rev. **106**, 1296 (1957); J. Schwinger, *Proceedings of the Seventh Annual Rochester Conference on High-Energy Nuclear Physics, 1957* (Interscience Publishers, Inc., New York, 1957), Session IX.

[2] D. B. Lichtenberg and M. H. Ross, Phys. Rev. **107**, 1714 (1957); **109**, 2163 (1958); and M. H. Ross and D. B. Lichtenberg, Phys. Rev. **110**, 737 (1958). N. Dallaporta and F. Ferrari, Nuovo cimento **5**, 111 (1957); R. H. Dalitz and B. W. Downs, Phys. Rev. **111**, 967 (1958).