a recent determination of the τ branching ratio[9] we found a Dalitz-pair frequency of $(0.41 \pm 0.07)\%$ of all K^+ decays, based on 36 Dalitz pairs found. This is to be compared with $(0.39 \pm 0.01)\%$ expected from recently published K^+ branching ratios[10] and the Dalitz-pair probability observed for π^0's produced in strong interactions.[11] The resulting product R_0P_0 is $(2.0^{+7.0}_{-2.0})\times 10^{-4}$, where P_0 is the neutral spion frequency, and R_0 is the Dalitz-pair frequency in the neutral spion decay. We applied the same test separately to τ' and $K_{\mu 3}$ decays. In the first exposure we found 61 Dalitz pairs (56 expected) among 2393 τ' decays and 10 (12.4 expected) among 1062 apparent $K_{\mu 3}$ decays. In the second exposure we have not yet determined the Dalitz pair efficiency. The resulting products R_0P_0 are $(2.0^{+3.0}_{-2.0})\times 10^{-4}$ for τ' decay, and $(0^{+0.7}_{-0})\times 10^{-4}$ for $K_{\mu 3}$ decay.

We thank the Saclay-CERN hydrogen bubble chamber group and the CERN proton-synchrotron staff for the exposure. We thank Dr. R. Cester for stimulating discussion.

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*On leave from the Lawrence Radiation Laboratory, Berkeley, California.

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SMALL-ANGLE CHARGE EXCHANGE OF π^- MESONS BETWEEN 6 AND 18 GeV/c

A. V. Stirling, P. Sonderegger, J. Kirz,* P. Falk-Vairant, O. Guisan, C. Bruneton, and P. Borgeaud
Centre d'Etudes Nucléaires de Saclay, Saclay, France

and

M. Yvert, J. P. Guillaud, C. Caverzasio, and B. Amblard
Institut du Radium, Orsay, France

(Received 25 March 1965)

Charge-exchange processes in the region of the highest available accelerator energies have gained considerable attention during the past year.[1-5]

These reactions provide critical tests of the currently popular exchange models of high-energy strong-interaction physics. For models investigating one-particle intermediate states in the crossed channels, there are stringent limitations: Only nonstrange mesons with isotopic spin 1 can be exchanged for low momentum transfers. For K-nucleon and π-nucleon charge exchange there is the further condition that the spin and parity of the intermediate state must be of the series 0^+, 1^-, 2^+, etc. Finally, for π-nucleon charge exchange the additional limitation on G parity excludes all but the ρ from the list of particles with known quantum numbers. Cross sections for $\pi^- + p \rightarrow \pi^0 + n$ have been calculated using Regge-pole theory[6,7] and one-particle exchange with absorption.[8-10]

Supposing the exchange of one meson only, Regge-pole theory requires a shrinking of the forward peak. Non-Reggeized exchange models investigated so far predict purely real forward scattering amplitudes, and energy-independent cross sections for vector-meson exchange.

The cross section at 0° can be calculated using an unsubtracted dispersion relation and the optical theorem from π^+p and π^-p total cross-section data. This method has been used to verify the consistency of experiment with theory at lower energies.[11-12]

We report here the results on π^-p charge-exchange scattering at 5.9, 9.8, 13.3, and 18.2 GeV/c. The experiment was performed at the CERN proton synchrotron.

The π^- beam was defined by a counter telescope and two thin-plate spark chambers. The contamination by other negative particles was electronically removed. The liquid-hydrogen target was surrounded by lead-scintillator sandwiches containing 4 radiation lengths of lead in anticoincidence with the beam counters. The beam entered through a hole in this anticoincidence shield. In the forward direction there was no lead, permitting γ rays from π^0 decay to escape, and to be detected as showers in a third spark chamber placed further downstream. This chamber had dimension of 50×50 cm^2 and contained 12 radiation lengths of lead distributed among 26 plates. Target length and distance between target and γ detector were changed roughly proportionally to momentum (30 and 250 cm at 9.8 GeV/c).

The spark chambers were triggered each time a π^- meson entered the target, and only neutral secondaries escaped, γ rays being further limited to a solid angle covered by the heavy spark chamber. About half of the pictures contain two shower events, and for these the coordinates of the beam track in the thin-plate chambers as well as the first spark of each shower in the lead-plate chamber were measured. An estimate of the relative energy of the two γ rays was recorded for each event, based on the number of sparks in their showers.

Between 7000 and 16 000 2γ events have been measured at each of the four beam momenta studied.

In addition to trivial corrections, the following sources of biases and background were considered:

(1) Near $t=0$ there is no particular bias, except the one due to the rapidly varying neutron detection efficiency in the anticoincidence counters (0 at $t=0$, 10% at $t=-0.02$, 4% for $t<-0.1$). This effect was calculated and checked experimentally by measuring the efficiency of the counters for 14-MeV neutrons.

(2) By using photographs of π^- mesons traversing the whole apparatus, we were able to align the geometry to ±2 mm. The corresponding momentum-transfer error is negligible compared to our resolution. The ambiguity in the reconstruction of the π^0 line of flight was removed in more than 50% of the events by the estimate of the relative energy of the two γ rays. The cases where the energies are so closely equal that such an estimate is unreliable correspond to that region of the kinematics where the two solutions are almost identical. Here we used both solutions weighted according to the differential cross section. The reconstitution uncertainty is ±2.5 mrad at 10 GeV/c and gives the main contribution to the angular resolution at $-t<0.1$. At larger t the resolution is due to the finite target size ($\Delta t=\pm 0.1t$).

(3) The possible contamination from inelastic events (e.g., $\pi^0\pi^0 n$ with two photons escaping detection) was studied by comparing the experimental distribution of the opening angle of the two γ rays with the one expected for elastic events, obtained using a Monte-Carlo program. An equivalent way of examining the purity of the sample is to compare the π^0 angular distributions obtained for different cuts on the opening angle. This method gives no evidence for inelastic contamination, except at 18 GeV/c where a small effect was observed and corrected for. To study the possible effect of peripheral π^0 production in quasielastic reactions [such as $\pi^- + p \to \pi^0 + N^*(1238)$], where the low-energy recoil particles escaped detection in the anticoincidence shield, the configuration of this shield was varied in the 6- and 13-GeV/c exposures. With different thicknesses of lead from 0 to 8 mm providing the first layer of the sandwiches, we measured the triggering rate and the percentage of two-shower pictures and found no evidence for such quasielastic events. We conclude that background from inelastic and quasielastic reactions is less than 6% (less than 15% at 18.2 GeV/c).

(4) Nonhydrogen background at all energies is below 7%, and is corrected for on the basis of target-empty measurements.

(5) The amount of 1γ events/2γ events was of the order of 3-5%. This effect can be explained and does not give further errors on the π^0 results.

The results on the differential cross sections are shown in Table I and Fig. 1; in Fig. 1(a) the cross sections have been multiplied by the beam momentum $p_{\pi^-}^{(\mathrm{lab})}$. The errors are

Table I. Differential and total cross section for $\pi^- + p \rightarrow \pi^0 + n$ at 5.9, 9.8, 13.3, and 18.2 GeV/c; further data as explained in the text.

$-t \pm \Delta(-t)$ [(GeV/c)^2]	$d\sigma/dt$ [μb/GeV/c)^2] 5.9 GeV/c	9.8 GeV/c	13.3 GeV/c	18.2 GeV/c
0.01±0.005	374 ±13	216 ±10	195 ±6	141 ±8
0.03±0.005	430 ±13	251 ±10	203 ±6	144 ±8
0.05±0.005	411 ±13	247 ±10	215 ±6	144 ±8
0.07±0.01	412 ±13	235 ±10	189 ±6	125 ±7
0.09±0.01	397 ±13	218 ±10	174 ±5	120 ±7
0.12±0.02	332 ± 9	175 ± 6	136 ±3	94 ±5
0.16±0.02	252 ± 8	125 ± 5	94 ±2.5	60 ±4
0.21±0.03	164 ± 6	87 ± 4	60 ±2	41 ±3
0.28±0.03	85 ± 4	43 ± 2	30.4±1.6	17.5 ±2
0.36±0.04	32 ± 2	17 ± 1.8	9.9±0.6	5.5 ±1
0.45±0.04	12.4± 1.5	8.0± 1	3.5±0.4	1.6 ±0.4
0.55±0.05	5.7± 1.0	3.7± 0.7	0.9±0.3	0.5 ±0.2
0.65±0.06	6.1± 1.0	2.9± 0.7	1.5±0.3	0.2 ±0.2
0.80±0.07	8.8± 1.4	3.5± 0.6	1.5±0.2	0.25±0.2
σ_T[a]	87±4	48±2.5	36±2	24±2.5
$(d\sigma/dt)(0)$	375±30	207±30	188±20	134±15
B (slope)[b]	11.2±0.4	10.5±0.4	11.2±0.5	12.5±0.5
$[\mathrm{Im}T(0)]^2$[c]	170±30	110±30	80±25	60±25
$\mathrm{Re}T(0)/\mathrm{Im}T(0)$	1.10±0.15	0.95±0.25	1.15±0.20	1.15±0.25

[a] In μb. [b] In (GeV/c)^2. [c] In μb/(GeV/c)^2.

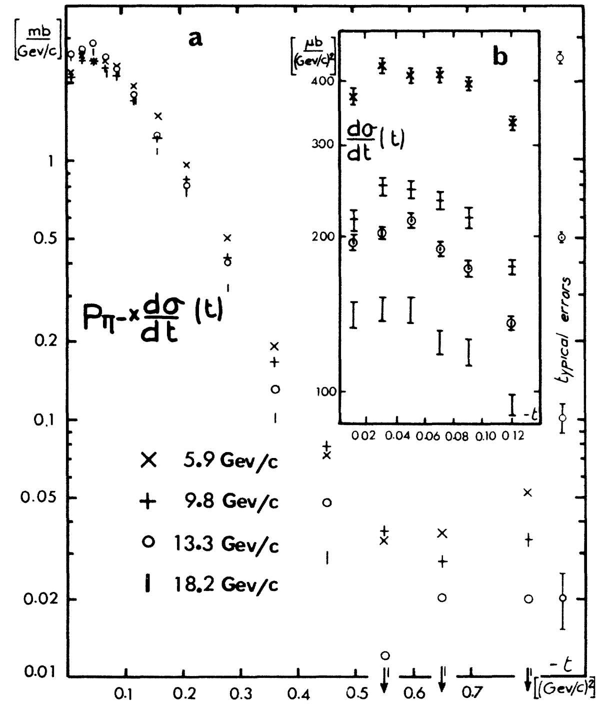

FIG. 1. (a) $(P_{\pi^-})(d\sigma/dt)(t)$ for the reaction $\pi^- + p \rightarrow \pi^0 + n$ at 5.9, 9.8, 13.3, and 18.2 GeV/c. Typical errors are shown or the right. (b) $(d\sigma/dt)(t)$ in the region of the forward peak.

statistical only. The resolution Δt is given in Table I and is independent of energy.

Assuming that the forward peak contains the bulk of the total charge-exchange cross section, we have listed the value

$$\sigma_T = \int_0^{-0.5} dt \frac{d\sigma}{dt}(t).$$

The error on σ_T includes a normalization and background subtraction uncertainty of ±5% (±10% at 18.2 GeV/c).

Using the least-squares method, we fitted an exponential of the form Ae^{Bt} to the data for $0.2 < -t < 0.5$ (GeV/c)^2, and a parabola in the region $-t < 0.07$. The resulting slopes B, and the extrapolated values at $t = 0$, respectively, are also indicated in Table I.

The forward cross section $(d\sigma/dt)(0) = |T|^2$, as well as the separate contributions of the real and the imaginary parts of the forward scattering amplitude T, are plotted in Fig. 2 as a function of momentum. The values of $(\mathrm{Im}T)^2$ were calculated from π^+p and π^-p total cross sections σ_+ and σ_-,[13] using the optical theorem which reads

$$(\mathrm{Im}T)^2 = (1/32\pi)(\sigma_- - \sigma_+)^2.$$

A smooth fit to the $(\sigma_- - \sigma_+)$ data given in reference 11 (curve b in Fig. 2) was used in order to extract the real part:

$$(\mathrm{Re}T)^2 = (d\sigma/dt)(0) - (\mathrm{Im}T)_{\mathrm{fit}}^{\ 2}.$$

One value for $(\mathrm{Re}T)^2$ was derived from the difference between the measured real parts for π^-p and π^+p elastic scattering.[14] The values for $(\mathrm{Im}T)_{\mathrm{fit}}^{\ 2}$ and for the ratio $\mathrm{Re}T/\mathrm{Im}T$ (the positive sign being taken from dispersion relations) are also listed in Table I.

From the data presented, the following conclusions can be drawn:

(1) At all momenta, the cross section bends downwards towards $t = 0$, its maximum being situated at $-t = 0.04$. Such a behavior has been noted in K^-p charge exchange also.[5] It is different from the pure exponential form of elastic scattering at small t. The presence of a strong spin-flip amplitude as suggested by the ρ-exchange model[10] could explain this effect.

(2) Predictions for the cross section and the real part at $t = 0$ have been calculated by Höhler and Giesecke[11] (curves a and c in Fig. 2), who assumed dispersion relations and a Regge-pole-like asymptotic behavior of the amplitude, $(\sigma_- - \sigma_+) \sim \mathrm{const}/\sqrt{p}$. The results are essentially

$$(d\sigma/dt)(0) \simeq \mathrm{const}/p_{\pi^-}^{\ \mathrm{lab}} \text{ and } \mathrm{Re}T/\mathrm{Im}T \simeq 1.$$

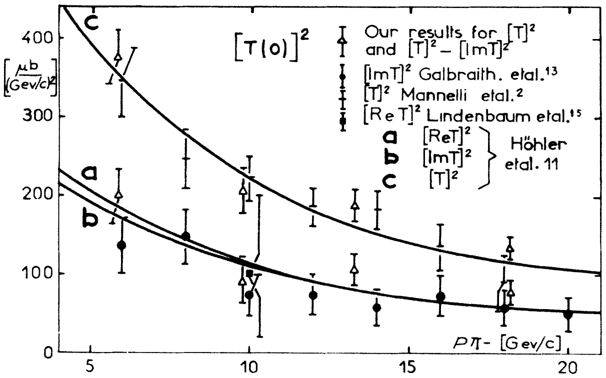

FIG. 2. The forward differential cross section $(d\sigma/dt)_{t=0}$ and the contributions of the real and imaginary parts of the scattering amplitude $(\mathrm{Re}T)^2$ and $(\mathrm{Im}T)^2$. Curve b is a fit of the form const/P_{π^-}.[11] Curves a and c are predicted by the dispersion relation of reference 11. Also shown are results of references 2 and 15.

The agreement with experiment is seen to be reasonably good. Results of a similar experiment[2] have been interpreted in an analogous way by Logan.[6]

(3) The differential cross section at momentum transfers up to 0.5 $(\mathrm{GeV}/c)^2$ shows roughly a $1/p$ dependence, as can be seen from Fig. 1. Furthermore, in the exponential region $0.2 < -t < 0.5$ there is some indication of a possible shrinkage of the forward peak with increasing energy, which, however, is within the errors of the experiment. The average slope is similar to the one found in elastic-scattering experiments.[15] Distorted-wave Born-approximation calculations carried out so far[8-10] fail to predict the absolute value and the shape of the differential cross section, presented above.

(4) The data show a definite change in behavior of the differential cross section at $-t \geqslant 0.5$ $(\mathrm{GeV}/c)^2$. To further investigate the possible existence of a second peak, a special experiment was performed, with a sensitive region $0.2 < -t < 4$ $(\mathrm{GeV}/c)^2$. The analysis is in progress.

All the above conclusions are in agreement with those of the Pisa-M.I.T. collaboration.[2]

We wish to thank Professor A. Berthelot and Professor J. Teillac for their continued encouragement and interest, and Professor V. Weisskopf and Professor P. Preiswerk for the hospitality we enjoyed at CERN. The generous and skilled help of the CERN proton synchrotron staff made the experiment possible and is gratefully acknowledged. We have profited from numerous discussions with Professor L. Van Hove and Professor G. Höhler and other theorists at CERN and Saclay, as well as Dr. W. Rarita and Dr. R. J. N. Phillips in Berkeley. One of us (J.K.) wishes to thank the U. S. Air Force Office of Scientific Research for financial support under a NAS-NRC Postdoctoral Fellowship.

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*Present address: Lawrence Radiation Laboratory, Berkeley, California.

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ABSORPTION TIME OF NEGATIVE K^- MESONS IN LIQUID HYDROGEN*

R. Knop, R. A. Burnstein, and G. A. Snow

University of Maryland, College Park, Maryland

(Received 8 April 1965)

A measurement of the absorption time of negative K^- mesons in liquid hydrogen can be used as an indirect test of the validity of the prediction by Day, Snow, and Sucher[1] that stopping K^- mesons are absorbed predominantly from s states of high principal quantum number n. Using this model of "Stark-effect" mixing, Bethe and Leon[2] have predicted that the K^--meson cascade time (from initial atomic formation to nuclear s-wave absorption) is $T_1 = (2.4^{+0.8}_{-1.3}) \times 10^{-12}$ sec. On the other hand, if there were no "Stark-effect" mixing, their calculations of the Auger and radiative transition rates indicate that the K^--meson cascade time would be $T_2 \approx 30 \times 10^{-12}$ sec.

In this note we report a measurement of this cascade time. We find $T_{\text{expt.}} \lesssim 4 \times 10^{-12}$ sec in good agreement with the "Stark-effect" prediction, T_1.

The experimental method consists in observing the τ decay mode of K^- mesons in the Saclay 81-cm hydrogen bubble chamber exposed at CERN.[3,4] The τ mode of decay is the only channel in which all the decay energy of the K^- appears as charged tracks in the bubble chamber. This allows the K^- momentum at decay to be determined with an accuracy of ±5-10 MeV/c. Such momentum resolution implies that in-flight K^- mesons with velocity $\beta > 0.02$ can be distinguished from at-rest K^- decays. [In traversing the internal $\beta = 0.02$ to atomic capture, the K^- meson spends a time $\sim 1 \times 10^{-12}$ sec.[5] Any K^- mesons that decay in this interval form an irreducible but small background to the number of decays at rest.] A similar method has already been employed to determine the K^- capture time in liquid helium.[6]

The scanning procedure consisted in locating and recording a number of different kinds of K^--meson events. One of these configurations was the τ decay mode of the K^- meson. Since we are interested in finding the τ decays at rest, we have devised a procedure which retains all the τ decays at rest and rejects most of the τ decays in flight. This drastically reduces the number of events to be measured. The procedure can be understood by referring to Fig. 1, which shows a typical τ decay at rest and a typical τ decay in flight. The test is applied to two of the three stereo views of the film and involves placing a straight edge across the τ decay vertex and adjusting the straight edge in an attempt to determine whether all three pion tracks fall in the half-plane to one side of the straight edge. Those events that clearly pass the test cannot be τ decays at rest, since momentum would not be conserved, and are classified as definite τ decays in flight.