PRODUCTION OF π^0 MESONS IN COLLISIONS BETWEEN 2.8-Bev/c π^- MESONS AND PROTONS

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Submitted to JETP editor July 2, 1960

J. Exptl. Theoret. Phys. (U.S.S.R.) **39**, 1232-1236 (November, 1960)

The production of π^0 mesons in the $\pi^- + p \rightarrow m\pi^0 + n$ ($m = 1, 2, 3$) reactions was investigated at $p_{\pi^-} = 2.8$ Bev/c in a 17-liter bubble chamber filled either with a propane-xenon or a freon 12- freon 13 mixture. The cross section for hydrogen was determined by the difference method as (2.2 ± 0.3) mb. The mean number of γ rays per interaction is 4.0 ± 0.4. The angular distribution of the γ rays in the c.m.s. is anisotropic and possesses a sharp peak in the forward direction. The small cross section for exchange scattering, $\sigma(\pi^- + p \rightarrow \pi^0 + n) = (0.20 \pm 0.25)$ mb, indicates that, for the given π^--meson energy, the partial interaction cross sections with isotopic spins $^3/_2$ and $^1/_2$ are equal. The cross sections for processes involving the production of two or three π^0 mesons are estimated by analyzing the distribution of the events with respect to the number of γ quanta.

INTRODUCTION

THE multiple production of mesons in π^-p collisions at π-meson energy > 1 Bev has been studied by a number of investigators. In experiments with diffusion chambers in a magnetic field and filled with hydrogen, the meson production in π^-p collisions was studied at a π^--meson energy of 5 and 1.85 Bev.[1,2] Walker[3] carried out similar experiments using nuclear emulsions for 4.5-Bev π mesons. As a result of these investigations, the angular and momentum distributions of π mesons, as well as the distributions of mesons with respect to various charged states, have been obtained. The most complete data relate to the production of charged mesons. The reactions accompanied by a simultaneous production of charged and neutral mesons have only been partially investigated. Reactions of the type

$$\pi^- + p \rightarrow m\pi^0 + n \qquad (1)$$

where only neutral particles are emitted have not been investigated. A logical interpretation of the data on the multiple production of π mesons becomes possible if one makes an assumption about the ratio of the production cross sections for different isotopic spins of the system. In particular, the number of events of type (1) was determined in references 1 and 2 by using such a method.

It would be of interest to obtain direct data on the production of π^0 mesons in these reactions, and on the magnitude of the exchange scattering of π^- mesons with energies > 1 Bev.

The cross sections for processes of the type (1) were measured by us for 2.8-Bev/c π^- mesons by means of a bubble chamber[4] filled with a heavy hydrogen-containing liquid.[5] The measurements were carried out with the extracted π^--meson beam of the proton synchrotron of the Joint Institute for Nuclear Research.

1. EXPERIMENTAL METHOD

About 3000 stereoscopic photographs were taken in experiments with the π^--meson beam, using a bubble chamber filled with a propane-xenon mixture. The cross section for hydrogen was determined by the difference method. In order to determine the background due to the quasi-free collisions of π^- mesons with protons in the nuclei, 2800 additional stereoscopic photographs taken in analogous experiments with the π^- beam and the same bubble chamber, but using a mixture of freon 12 (CCl_2F_2) and freon 13 ($CClF_3$), were analyzed.

All photographs were scanned by three independent observers. In the scanning, prongless stars were noticed, i.e., events where, in the observation region, a π^- meson track stopped abruptly without any visible nuclear-interaction products. Usually, it was possible to correlate such a point of track disappearance with one or more electron-positron conversion pairs appearing as a result of the process (1) with consecutive decays $\pi^0 \rightarrow 2\gamma$.

In order to find the absolute cross section for the process, the total number of π mesons passing through the working volume of the chamber was counted. Particles were counted in 10 out of every 50 squares. The total number of π mesons was found to equal 42,300 and 38,300 for the propane-xenon and freon fillings, respectively. A 5-cm x 15-cm lead collimator was placed at the entrance to the chamber. The strict delimitation of the beam region considerably increased the conversion efficiency, but also the relative fraction of μ mesons in the beam. The admixture of μ mesons in the beam was not measured and, therefore, to compute the cross section, the ratio of the total number of interactions to the given number of π-meson passages was determined.

Estimates of possible background events were made. Possible imitating processes are events of the types

$$\pi^- + p \rightarrow \Lambda^0 + K^0 + m\pi^0, \quad (2)$$

$$\pi^- + p \rightarrow K^0 + \tilde{K}^0 + n\pi^0 \quad (3)$$

on a free proton or on a weakly-bound proton of a nucleus. About 120 events of the V-decay type were detected in 3000 pictures. It was found that the number of events in which K^0 mesons or Λ^0 hyperons are produced, and which can be regarded as reactions (2) or (3), is less than 5%. Such a correction amounts to not more than 2 to 3% of the events studied, and was not taken into account in the final results.

The number of chance electron-positron pairs directed towards the point of disappearance of π^- mesons was estimated. The estimate was obtained by noting that, among the 120 V-decay events detected in the photographs, not a single electron-positron pair was directed towards the vertex of the V event. This makes the probability of a chance superposition less than 1% of the total number of detected electron-positron pairs directed towards prongless stars.

2. EXPERIMENTAL RESULTS

As a result of the multiple scanning of the photographs, 125 prongless stars were found in the propane-xenon mixture, and 102 in the freon filling. The distribution with respect to the number of electron-positron pairs directed towards the point of disappearance of the π^- mesons is given below:

Number of pairs $e^+ + e^-$	0	1	2	3	4	5	6
Number of events in the propane-xenon mixture	13	30	41	26	9	5	1
Number of events in the freon mixture	13	52	22	11	3	1	—

The angle θ_γ with the direction of the incident π mesons was determined for each pair. In order to obtain data on the angular γ-ray distribution, the detection efficiency was calculated by two methods. In the first method, the maximum possible γ-ray path length in the working volume of the chamber was measured and the probability of observing a given pair was determined from the known conversion length (equal to 19 and 30 cm for the two working liquids, respectively). In the second method, the mean detection efficiency of the γ rays in the chamber was calculated for different angles of emission θ_γ with an electronic computer.

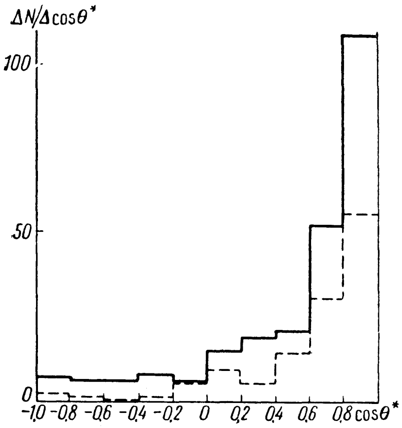

FIG. 1. Angular distribution of γ rays in the c.m.s. without taking the detection efficiency into account: solid curve – propane and xenon, dashed curve – freon.

The angular γ-ray distributions in the pion-nucleon c.m.s., obtained without taking the detection efficiency into account, are shown in Fig. 1. The angular distributions obtained with account of the efficiency are shown in Figs. 2 and 3. Both methods of calculating the efficiency gave similar results.

From the observed number of events we calculated the probabilities for the production of prongless stars on the nuclei of C, F, Cl (freon) and H, C, Xe (propane-xenon mixture). These were found to equal respectively (0.93 ± 0.1)% and (1.6 ± 0.15)% of the total cross section for the inelastic interaction of π^- mesons with nuclei. The cross section per free proton calculated from these data is (2.2 ± 0.3) mb. In calculating the results for freon, it was assumed that the charac-

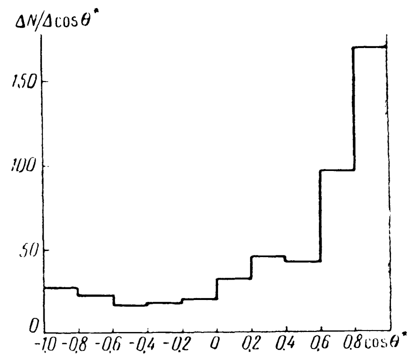

FIG. 2. Angular distribution of γ rays from reaction (1) in the c.m.s. (propane-xenon).

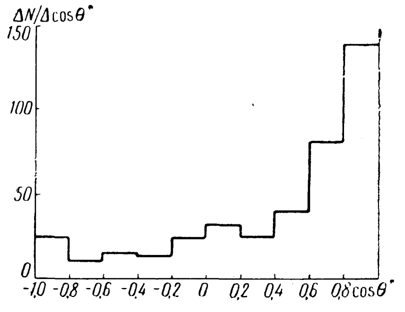

FIG. 3. Angular distribution of γ rays from the reaction $\pi^- + C \rightarrow m\pi^0 + C'$ in the c.m.s. (freon).

ter of the nuclear interactions differs little for a lighter nucleus (C) and for a heavier nucleus (Cl). For the xenon nuclei, it was assumed that the production cross section for prongless stars on xenon is proportional to the number of protons in the nucleus.* It is important to note that, out of 125 events detected in the xenon-propane mixture, two thirds occurred on free protons and only one third on the bound protons of the nuclei. Thus, the results depend little on the assumptions made in the calculation.

From a comparison of the angular γ-ray distributions obtained for the two different mixtures (see Fig. 1), it can be seen that the distributions are identical within the limits of experimental error. One can therefore assume that Fig. 2 represents the distribution of γ rays originating in the decay of π^0 mesons produced on free protons.

The mean number of γ rays per interaction of the above type equals 4.0 ± 0.4, i.e., two π^0 mesons are on the average produced per collision.

From six events in which five or six conversion pairs were observed (5γ, 6γ), it was found that the number of events of the type $\pi^- + p \rightarrow 3\pi^0 + n$ lies between 30 and 60. Moreover, from the number of events in which only one pair was observed (1γ), it was found that the number of exchange scattering events $\pi^- + p \rightarrow \pi^0 + n$ is not greater than 25. Such an estimate made it possible to determine the cross section for the process (1) for m = 1, 2, and 3:

$$\sigma_{\pi^0 n} = (0.2 \pm 0.25)\ \text{mb},\quad \sigma_{2\pi^0 n} = (1.3 \pm 0.4)\ \text{mb},$$

$$\sigma_{3\pi^0} = (0.7 \pm 0.4)\ \text{mb}.$$

The mean number of γ rays calculated from these cross-section values is 5.6 ± 0.6, which disagrees with the value 4.0 ± 0.4 given above. It is natural to ascribe this discrepancy to the low detection efficiency of the reaction $\pi^- + p \rightarrow 3\pi^0 + n$, and to the resulting large statistical errors in the cross sections.

*We have also made use of preliminary results, obtained in a xenon bubble chamber, for which we thank E. V. Kuznetsov. According to these data, the ratio of prongless stars to the total number of interactions is equal to (0.5 ± 0.2)% per xenon nucleus.

3. DISCUSSION OF RESULTS

As can be seen from Figs. 2 and 3, the angular γ-ray distribution in the c.m.s. is strongly anisotropic. We can observe one section in the distribution that is strongly peaked in the forward direction ($\cos\theta^* \gg 0.6$, where θ^* is the angle in the c.m.s.), while another section is isotropic. It should be mentioned that the angular π^0-meson distribution will practically coincide with the γ-ray angular distribution provided the energy spectrum of the π^0 mesons is sufficiently hard, which is evidently true for the energy of π^- mesons used. The conclusions reached concerning the angular γ-ray distribution will then apply to the same extent to the angular distribution of π^0 mesons produced in reaction (1). Similar regularities detected by us on π^0 mesons were also observed for charged mesons.[1,2]

Reaction products	Probability of a given reaction in percent of the total cross section for inelastic interaction	
	According to statistical theory	Experimental values
n 0	2.4	1 ± 1.2
n 00	5.3	5.9 ± 1.8
n 000	2.6	3.2 ± 1.8
n 0000	0.4	–
Total	10.7	10.1 ± 1.4

It is known that calculations based on the statistical theory of multiple π-meson production do not explain the anisotropy of the angular distribution, although they are in good agreement with the data on the multiplicity of the production processes.[6] The same is true for our results. Maksimenko,[7] using statistical theory, calculated that for 2.8-Bev π^- mesons the processes of the type (1) should amount to 10.7% of the cross section for inelastic interactions of π^- mesons with protons. This is in good agreement with our experimental result of (10.1 ± 1.4)%. A satisfactory agreement with the statistical theory can also be obtained by comparing the calculations on the multiplicity of process (1) with the experimental data obtained (see table), although large statistical errors in the cross section make such a comparison not very effective. Moreover, the observed anisotropy in the angular distribution of π^0 mesons cannot be explained by a statistical theory. An interesting possibility for explaining the peculiarity in the angular π-meson distribution was considered by Barashenkov.[8] It was demonstrated by him that the resulting asymmetry in the angular distribution of the mesons produced can be explained by assuming that the peripheral collisions amount to $\gtrsim 20\%$ of the total cross section for $\pi^- p$ collisions.

The cross section for exchange scattering can be written in terms of the amplitudes f and g corresponding to isotopic states with $T = 3/2$ and $T = 1/2$ respectively:

$$\sigma(\pi^- + p \to \pi^0 + n) = \frac{2}{9}[f - g]^2.$$

Okun' and Pomeranchuk[9] have drawn attention to the fact that, at high energies, the exchange-scattering cross section should amount to only a small fraction of the total cross section for inelastic scattering, and that, consequently, $f \approx g$. From the data of the present experiment, we can conclude that, even for $\sim$3-Bev π mesons, the reaction probabilities for channels with different isotopic spins are practically equal. Using the dispersion relations, we can also show that the differential charge-exchange cross section at 0° decreases sharply with increasing π-meson energy from 0.8 to 2 Bev.[10] Similarly, the total cross section for exchange scattering should also decrease, a fact which is also confirmed by the results obtained.

In conclusion, the authors would like to thank Academician A. I. Alikhanov for help and support in the experiment, and Academician V. I. Veksler for enabling us to carry out the present experiment. We would like to thank the synchrotron operation team, who made it possible to execute the work, and also Yu. S. Krestnikov, Yu. I. Makarov, and N. S. Khropov for help in carrying out the measurements. We are indebted to N. G. Birger for helpful comments, to V. M. Maksimenko for calculating the results of the statistical theory, to I. S. Bruk for providing the facilities of the M-2 electronic computer of the Institute for Electronic and Control Machinery, U.S.S.R. Academy of Sciences, and to G. M. Adel'son for carrying out the computations.

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Translated by H. Kasha
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