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Abstract

Full Text

Physics

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PRODUCTION OF CHARGED MESONS BY π^- MESONS WITH AN ENERGY OF 290 MeV ON HYDROGEN*

(Presented by Academician L. A. Artsimovich, March 14, 1960)

At the present time, information on inelastic (π^-—p) interactions has been obtained mainly in the region of primary-meson energies of 1 BeV and above ([1–4]). The small cross sections of these processes at lower energies make it difficult to obtain experimental data. At primary-meson energies in the interval 200–500 MeV there is either information concerning the production of charged mesons on complex nuclei ([5–8]), or data mainly only on the total cross sections for meson production on hydrogen, obtained with the aid of electronics ([9,10]). Comparison of the results obtained in the energy region 1–1.5 BeV with the predictions of the statistical theory and of the isobar model, which takes into account the resonant interaction of the π meson with the nucleon, showed that the isobar model is in better agreement with experiment ([17]). On the other hand, in a number of works attempts are made to interpret the experimental results from the point of view of the $(\pi - \pi)$ interaction.

The aim of the present work is to study the angular and energy characteristics of the secondary particles in the reaction

$$\pi^- + p \to \pi^- + \pi^+ + n \tag{1}$$

at a primary π^--meson energy equal to 290 MeV. The obtained angular and momentum distributions are compared with the predictions of Fermi's statistical theory and the Lindenbaum–Sternheimer isobar model.

The search for cases of meson production by mesons was carried out in emulsion chambers irradiated in a beam of π^- mesons from the synchrocyclotron of the Laboratory of Nuclear Problems of the Joint Institute for Nuclear Research. In all, three chambers were irradiated, consisting of 50, 80, and 100 emulsion layers of the NIKFI-BR type, with an area of 100×100 mm^2 and a thickness of 450 μ. Taking into account slowing down in the emulsion, the measurement results were referred to a primary-meson energy of (290 ± 15) MeV. During assembly of the chambers, a coordinate grid was applied to the surface of each layer by the

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Figure 1: Momentum distributions of secondary particles from the reaction $\pi^- + p \to \pi^- + \pi^+ + n$ in the c.m. system.

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contact-printing method; this made it possible reliably to continue the tracks of charged particles from one layer to another ([11]). When the emulsion layers were scanned "by area" under a microscope with magnification 225×, stops of π^+ and π^- mesons were recorded. The tracks of the charged mesons were then followed back to the acts of their production. This method made it possible effectively to register mesons with energies up to 70 MeV. The possible number of mesons from reaction (1) which, in the laboratory coordinate system, could have an energy greater than 70 MeV and were not registered did not exceed 7%.

As a result of searches for stopped π mesons and subsequent tracing back of their tracks, 1920 interactions of primary mesons in the photographic emulsion were registered. For further analysis, such cases were selected—cases in which the secondary charged particles were only two mesons, i.e., there were no other secondary charged particles and no recoil nucleus or electron emerging from the center of the "star." The identification of mesons that did not stop in the chamber was carried out in the same way as in Ref. ([12]). From the total number of events with secondary mesons, 135 events satisfying the requirements stated above were selected. In these cases the energies of the secondary mesons and their emission angles were measured. Assuming that the events correspond to reaction (1), in each case the momentum of the secondary neutron was determined and the difference Δp between the neutron momentum found from the law of conservation of energy and from the law of conservation of momentum was calculated. The cases ultimately counted as meson production on hydrogen according to reaction (1) were those for which the condition $\Delta p \leqslant 2\sigma$ was satisfied, where σ is the error in the measurement of Δp, determined by the spread of the energies of the primary mesons in the beam and by the inaccuracy in the measurements of the energies and emission angles of the secondary mesons. In all, 100 such cases were selected. The mean value of Δp for them was 38 MeV/c, which is 9%

Fig. 1. Momentum distributions of secondary particles from the reaction $\pi^- + p \to \pi^- + \pi^+ + n$ in the c.m. system (100 events). A—π-mesons, B—neutrons. Curve **1** was calculated according to statistical theory, **2**—according to the isobaric model. The curves were calculated for an incident-meson energy of 300 MeV.

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* Preliminary results of this work were reported by B. M. Pontecorvo in July 1959 at the Conference on High-Energy Particle Physics in Kiev.

Fig. 2

Figure 2: Fig. 2

of the momentum of the primary meson. Estimates showed that the possible admixture of "quasi-hydrogen" cases among the selected events is $\sim 20\%$. Each case was counted with a weight equal to $1/w_i$, where w_i is the probability of registering the stopping of that π-meson from whose track the given case was found. The probability of registering a π-meson, determined by the geometrical dimensions of the chamber, was calculated analogously to Ref. ([13]). The mean value of w_i in our cases was 0.5.

The estimate of the cross section of reaction (1) was made by comparing the number of meson-production events on hydrogen with the number of "stars" produced by π^--mesons in the same volume of emulsion, and also from the flux of primary mesons (the chemical composition and density of the emulsion were taken from the work of K. S. Bogomolov and M. F. Rodicheva (NIKFI)). The mean value of the cross section of reaction (1) at an energy of (290 ± 15) MeV from these two estimates is (0.61 ± 0.13) mbarn. Only the statistical error is indicated here. This result agrees with the data of Ref. ([10]), in which the cross sections of reaction (1) at primary-meson energies of 260 and 317 MeV are, respectively, (0.20 ± 0.12) and (0.75 ± 0.25) mbarn. The cross section of reaction (1) at an energy of 290 MeV, measured experimentally, is appreciably higher than the theoretical value (~ 0.1 mbarn) obtained in Refs. ([14,15]).

The momentum distributions of secondary π-mesons and neutrons in the center-of-inertia system (c.m.s.) of the colliding π^--meson and proton are presented

in Fig. 1. (In constructing the momentum and angular distributions, all secondary particles produced in the given event were taken into account with a weight determined by the probability of registering the pion by whose track this event was found.) For comparison, the same figure gives the theoretical distributions calculated from the formulas of statistical theory [16] and the isobar model [17] for an energy of the primary mesons equal to 300 MeV. The spectra of mesons and neutrons from reaction (1) agree, within the experimental errors, with the theoretical distributions. It should be noted

Fig. 2. Angular distributions of secondary particles from the reaction
$\pi^- + p \to \pi^- + \pi^+ + n$ in the c.m. system (100 events).
A—π^+-mesons, B—π^--mesons, V—neutrons

that the momentum spectra of the secondary particles calculated according to statistical theory and according to the isobar model at an energy of 300 MeV differ only insignificantly; therefore their comparison with the experimental results does not make it possible to give preference to either of them.

The angular distributions of pions and neutrons are shown in Fig. 2. In the c.m. system, the π^+- and π^--mesons are distributed anisotropically and, relative

Fig. 3. Angular distributions between the momenta of secondary particles from the reaction $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ in the c.m.s. (100 events)

Figure 3: Fig. 3. Angular distributions between the momenta of secondary particles from the reaction $\pi^- + p \rightarrow \pi^- + \pi^+ + n$ in the c.m.s. (100 events)

to the direction of the primary mesons, are emitted predominantly into the backward hemisphere. Neutrons in the overwhelming majority of cases fly into the forward hemisphere. The anisotropic and asymmetric angular distributions of the products of reaction (1) contradict the assumption of Fermi' s statistical theory.

As the energy of the primary meson increases from 290 MeV to 1.5 BeV, a sharp change is observed in the angular distributions of the secondary particles in reaction (1). Thus, for example, at energies of 1.4-1.5 BeV (1,3) the secondary neutrons in most cases fly backward, while the mesons are emitted predominantly into the forward hemisphere.

According to the angular and momentum distributions of the secondary particles, the production of an additional meson at an energy of 290 MeV occurs mainly in collisions of a π^--meson and a proton with a large transfer of momentum to the nucleon. Comparison of the results obtained with the results of work (4) shows that, with increasing collision energy in the processes of single pion production, the average momentum transfer to the nucleon decreases relatively.

The distributions of the angles between the momenta of the secondary particles are shown in Fig. 3. It is seen that pions and neutrons in the c.m. system fly predominantly in opposite directions: approximately 80% of the pions are emitted backward relative to the direction of flight of the neutron. In the distribution of the angles between the momenta of the secondary mesons, a rise is observed in the region of large angles.

From the analysis of the experimental data obtained in the present work, it follows that the momentum distributions, summed over all angles,

in the c.m.s., do not contradict either the statistical theory or the chosen model. The angular distributions are in contradiction with the assumption of Fermi' s statistical theory about an isotropic distribution of the reaction products in the c.m.s. To explain the asymmetry in the angular distributions of the secondary particles within the framework of the chosen model of Steinheimer and Lindenbaum, it is necessary to assume an asymmetric angular distribution of the "isobar" in the c.m.s., with its preferential emission forward relative to the direction of the primary meson.

Fig. 3. Angular distributions between the momenta of secondary particles from the reaction

$$\pi^- + p \rightarrow \pi^- + \pi^+ + n$$

in the c.m.s. (100 events)

As was noted in work (18), the study of the angular and energy distributions of secondary particles in reaction (1) near threshold may provide information about the $(\pi-\pi)$ interaction. For this purpose, further processing of the experimental results will be carried out.

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