SPECTRA OF CHARGED MESONS EMITTED AT 90° IN np *COLLISIONS INVOLVING* 600 MeV *NEUTRONS*

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The energy spectra of charged mesons emitted at 90° in the laboratory system as a result of the $n + p \rightarrow \pi^{\pm} + \ldots$ reaction induced by ~600-MeV neutrons are measured with an emulsion stack. The ratio of π^+- and π^--meson yields is measured, and found to equal 0.94 ± 0.10. The results agree with those obtained with a magnetic spectrometer [4].

THE investigation of the production of charged mesons in collisions between neutrons and protons encounters considerable difficulties due to the relatively low intensities of neutron beams from accelerators and the small cross sections of these processes (at the given energy). Certain complications arise also in the interpretation of the experimental results, owing to the broad energy distribution of the neutrons.

Therefore the reactions

$$n + p \rightarrow \pi^+ + n + n, \quad n + p \rightarrow \pi^- + p + p \qquad (1)$$

have been dealt with in only a few papers. At the same time, these reactions are of interest, for they alone can yield information on the value of the cross section σ_{01} (we are using Rosenfeld's classification [1]), one of the three partial cross sections used in the phenomenological resonance theory of meson production in nucleon-nucleon collisions.

The meson spectra in reactions (1) were investigated with nuclear emulsions at neutron energies 400 MeV [2] and 600 MeV [3]. Jodh [2] obtained the energy distribution of π^+ and π^- mesons at 90°. In Sidorov's study [3], the difficulties connected with the use of single photographic plates and decelerating filters did not make it possible to obtain reliable data on these spectra.

The most complete data on the reactions (1) at ~600 MeV, in a broad angle interval, were obtained with a magnetic spectrometer. Preliminary results of this work were already published [4] 1). When the electron procedure is used, it becomes necessary to introduce in the measured π-meson spectra several corrections for the registration of protons, muons, and electrons by the apparatus. The greatest of these corrections is the one which accounts for the electron admixture at large measurement angles. Consequently, the accuracy with which the pion spectra are measured at low energies and at these angles is greatly reduced.

In order to increase the reliability of the data in the indicated range of angles, we have measured by an independent method, using an emulsion stack, the spectra of $\pi^{\pm}$ mesons at 90° in the laboratory system. The emulsion method has made it possible to study more reliably the low-energy region at 90°, and in general to shift to somewhat lower energies of the registered pions.

The experiment was made with the synchrocyclotron of the nuclear problems laboratory of the Joint Institute for Nuclear Research. The experimental setup is shown in Fig. 1. The neutron beam passed through a collimator 50 mm in diameter in a 4-meter concrete wall. A liquid-hydrogen target-dewar, the same as used in [4], was placed in the path of the neutron beam. The mesons emitted from the target at 90° to the neutron-beam direction were gathered with a lead collimator in the shape of a slot 125 mm long and 10×100 mm in cross section, and were registered by the emulsion stack, which consisted of 20 type NIKFI-R 100×100 mm pellicles $400\,\mu$ thick. The pellicles

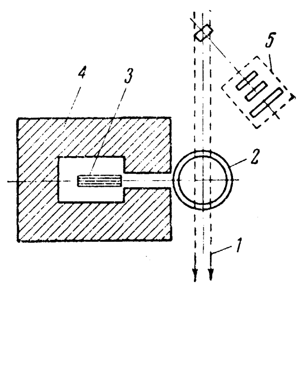

FIG. 1. Diagram of the experiment: 1 – neutron beam, 2 – vessel with liquid hydrogen, 3 – pellicle stack, 4 – lead shield, 5 – monitor telescope.

1)A detailed article is presently being readied for publication.

were equipped with markings [5] to be able to trace the track produced by the mesons in the stack. The angular resolution of the detector was $\pm 1.5°$. The hydrogen-filled target was irradiated for seven hours at a neutron-beam intensity $\sim 10^5$ neutron-$cm^{-2}\,sec^{-1}$.

The energy of the mesons entering the stack were determined from the range in the emulsion with allowance for multiple Coulomb scattering. The threshold energy of the registered mesons was 18 MeV and was determined by the amount of matter along the path of the mesons prior to entering the pellicle stack. The developed pellicles were scanned twice and independently under a microscope with magnification $7 \times 10 \times 1.5$. Four pellicles were scanned, in which 812 stopped π^+ mesons and 1238 stopped π^- mesons were registered (no "prongless stopped" π^- mesons were registered). The efficiencies for the registration of positive and negative pions were practically identical in our case and amounted to ~ 0.7 ($\epsilon_{\pi^+} = 0.74 \pm 0.08$, $\epsilon_{\pi^-} = 0.68 \pm 0.08$). The detected pions were tracked from the stopping point for 10—15 mm along the track, that is, to the place where the pion energy was already 20—25 MeV and multiple Coulomb scattering became insignificant. If the meson track did not "see" the target through the lead collimator, then it was discarded as a background meson. As a result of the tracking, there were left 424 π^+ mesons and 328 π^- mesons, which were classified as produced in the hydrogen target. To determine the reliability of such a selection, we tracked part of the mesons of different energies all the way to the exit from the chamber. The possible error in the selection of the mesons leaving the hydrogen target was found not to exceed 5%.

An experiment with a target without hydrogen was made under the same geometrical conditions. One pellicle of this stack was scanned and an analogous tracking procedure was used. The directional background from the empty target was the same for positive and negative pions and amounted to $\sim 20\%$. In constructing the energy spectra of the pions, we introduced corrections for the detector solid angle and for the $\pi^\pm$ meson knockout due to the nuclear interaction in the emulsion [6].

The ratio of the yield of positive and negative pions from np collisions, with allowance for all the corrections, was in our case 0.94 ± 0.10. In the calculation of this ratio we took into account the correction for the "prongless" stopped π^- mesons, which amount to $\sim 27\%$ for the emulsion [7]. The ratio obtained agrees with the results of [4] and indicates that there is no noticeable interference between the amplitudes corresponding to the partial cross sections σ_{01} and σ_{11}.

The l.s. energy spectra of the $\pi^\pm$ mesons are shown in Fig. 2. The spectra of the π^- mesons obtained in the present work agree within the limits of errors with the results obtained by the magnetic spectrometer method [4]. The somewhat smaller energy threshold of the registered mesons and the higher accuracy of the measurements at low energies make it possible to trace more accurately the form of the meson spectrum in this region as compared with the results obtained by the electron procedure. Within the limits of errors, the spectra of the positive and negative pions are the same.

The obtained pion spectra pertain to the neutron spectrum with a broad energy distribution [8]. However, as shown by the analysis, the results of the measurements can be attributed to a neutron energy ~ 600 MeV. The energy corresponding to the maximum of the experimental pion spectrum shifts insignificantly because of the energy scatter of the neutrons relative to the position of the maximum of distribution for the neutron energy ~ 600 MeV. The upper limit of the observed meson spectra is in agreement with the calculated maximum possible value of the pion energy.

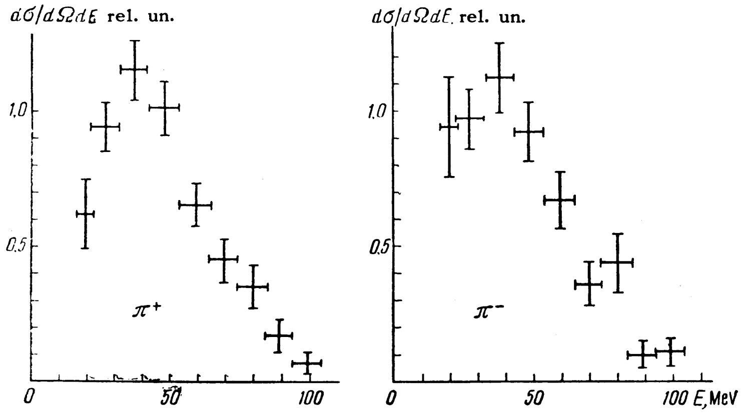

FIG. 2. Energy spectra of $\pi^\pm$ mesons from the reaction $np \to \pi^\pm + \ldots$, emitted at 90° in the laboratory system.

A characteristic feature of the obtained pion spectra is that the main part of the pions has energies that are considerably smaller than the maximum possible. The energy corresponding to the maximum of the energy distribution amounts to 40—50% of the maximum possible. An analogous picture is observed for these same energies for the spectra of the π^0 mesons which are formed in pp collisions [9]. At the same time, investigations of the $pp \to \pi^+ np$ reaction show that in this case the maxima of the π^+-meson spectra are shifted to a considerable degree towards the higher energies. In the latter reaction the mesons carry away 70—80% of the available energy [10].

All these facts agree with the resonance model of meson-production processes developed by Mandelstam [11]. It is assumed in the latter that the overwhelming contribution is made by the transition in which the produced pion and one of the nucleons interact in a state with $T = 3/2$, $J = 3/2$. As is well known, it gives the best description of all the experimental data for a proton energy in the region 500—700 MeV.

The cross section of the reaction (1), if expressed in terms of the partial cross sections, is equal to

$$\sigma(np \to \pi^{\pm} + \ldots) = {}^1/_2 (\sigma_{11} + \sigma_{01}). \qquad (2)$$

The resonant transitions make no contribution to the cross section σ_{01}. Therefore, from the point of view of the resonant model, this cross section should not give an appreciable contribution to the reaction (1). For σ_{11} there are possible resonant P_p transitions characterized by a spectrum with predominance of pions, which carry away an energy considerably smaller than the maximum possible. The results of the investigation of the reaction $pp \to \pi^0 pp$ [9], the cross section of which is expressed only in terms of σ_{11}, agree with these assumptions. The similarity between the spectra of the $\pi^{\pm}$ mesons obtained in np collisions with the spectra of the π^0 mesons in pp collisions (for nearly equal nucleon energy) can thus offer evidence that in both cases the resonant P_p transitions predominate and the contribution of the cross section σ_{01} to reaction (1) is apparently small.

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