Reports of the Academy of Sciences of the USSR

V. V. KRIVITSKII and A. A. REUT

1957

SovietRxiv

Fig. 1. Experimental arrangement

Figure 1: Fig. 1. Experimental arrangement

Abstract

Full Text

Reports of the Academy of Sciences of the USSR

1957. Volume 112, No. 2

PHYSICS

V. V. KRIVITSKII and A. A. REUT

PRODUCTION OF π^+ MESONS ON CARBON BY π^- MESONS WITH AN ENERGY OF 308 MeV

(Presented by Academician L. A. Artsimovich, 14 IX 1956)

The study of the process of meson production by mesons at energies close to the threshold of meson production is of considerable interest for clarifying the nature of the interaction of π mesons with nucleons and mesons. There are a number of works ($^{1-3}$) devoted to this question; however, it should be noted that in all the cited works the production processes were studied in nuclei of elements entering into the composition of photographic emulsion, as a result of which it was not possible to determine with which nucleus the interaction had occurred.

In the present work the production of π^+ mesons by negative π^- mesons on carbon was investigated. The experimental arrangement is shown in Fig. 1. A beam of π^- mesons with an energy of 308±12 MeV was deflected by the magnetic field of the synchrocyclotron and entered a collimator 50 mm in diameter and 2.7 m long, made in the yoke of the accelerator magnet (^{4}). After passing through the collimator, the π^- mesons struck the target, in which the production of positive π mesons occurred (the target was a graphite cylinder 60 mm in diameter and 40 mm high, mounted along the axis of the collimator). The beam of π^- mesons was then deflected by an auxiliary magnet and monitored by a monitor consisting of two scintillation counters.

Fig. 1. Experimental arrangement: 1 –π mesons, $E = 308$ MeV; 2 –protons, $E \simeq 670$ MeV; 3 –accelerator chamber; 4 –target; 5 –yoke of the synchrocyclotron magnet; 6 –auxiliary magnet; 7 –photographic plates; 8 –graphite target; 9 –telescope

Fig. 2. Geometry of the experiment. 1—graphite target; 2—aluminum wedges; 3—photographic plates

Figure 2: Fig. 2. Geometry of the experiment. 1—graphite target; 2—aluminum wedges; 3—photographic plates

The energy of the π^- mesons was determined from ranges in copper, and also with the aid of a current-carrying wire in the magnetic field. The uncertainty in the energy value is due to the initial energy inhomogeneity of the beam, the slowing down of mesons in the target, and the inaccuracy in determining the ranges.

To determine the intensity of the π^--meson beam, electron-sensitive photographic plates placed inside the collimator were used. In the work described, beams with intensities of approximately 150 and 300 cm^{-2} sec^{-1} were used.

Registration of the π^+ mesons was carried out with photographic plates having an emulsion layer thickness of 280 μ, mounted on aluminum wedges. The geometry of the experiment (Figs. 1 and 2) was chosen so that the photographic plates recorded mainly π^+ mesons emerging from the target at a mean angle of 90° to the direction of the π^--meson beam.

The number of π^+ mesons stopped in the emulsion was determined from the number of $(\pi - \mu)$ decays. In doing so, only those $(\pi - \mu)$ decays were counted in which the μ-meson track did not leave the emulsion; otherwise the decay was regarded as doubtful. The efficiency of recording $(\pi - \mu)$ decays by the photographic plates used was calculated and was found to be 0.25.

It is important to note that if, in experiments carried out on nuclei in a photographic emulsion, the fact of meson production can be asserted only when two π mesons are observed, then the method described permits such a conclusion to be drawn from only one π^+ meson (in the latter case the plate is simply an "indicator" of π^+ mesons). It is true that the appearance of a π^+ meson when carbon is irradiated with π^- mesons may also be due to two successive first-order processes ($\pi^- \to \pi^0$, $\pi^0 \to \pi^+$) in one and the same nucleus (a change in the sign of the charge of the π meson); however, the probability of such an event is apparently small, and therefore it may be neglected. In the case of irradiation of hydrogen with π^- mesons this possibility, of course, is absent.

Fig. 2. Geometry of the experiment. 1—graphite target; 2—aluminum wedges; 3—photographic plates

The plates were examined under a microscope at a magnification of 300×. In an area of photographic emulsion of 300 cm^2, 16 $(\pi - \mu)$ decays were found. The results of the observations are presented in Fig. 3. The largest number of observed $(\pi - \mu)$ decays corresponds to an energy of the produced π^+ mesons of 30–50 MeV. This result is explained mainly by the experimental conditions: mesons with energy less than 30 MeV stopped in the target itself or in the

Fig. 3. Distribution of $(\pi - \mu)$ decays along the length of the photographic plate

Figure 3: Fig. 3. Distribution of $(\pi - \mu)$ decays along the length of the photographic plate

wedges and therefore were not recorded by the photographic emulsion; mesons with energy greater than 50 MeV, because of the geometry of the experiment (small solid angle), were recorded in insignificant numbers. Therefore, in the calculation only 12 cases of $(\pi{-}\mu)$ decays were taken into account, corresponding to the energy interval 30–50 MeV, in which the meson-production cross section was assumed to be constant.

Fig. 3. Distribution of $(\pi{-}\mu)$ decays along the length of the photographic plate

The calculation of the differential cross section for the production of mesons by mesons was carried out using the formula

$$\frac{d^2\sigma}{dE\,d\omega} = \frac{N_{\pi^+}}{N_{\pi^-} ntd[dE/dR]_E \eta} \frac{1}{(S/r^2)},$$

where N_{π^+} is the number of $(\pi - \mu)$ decays found; N_{π^-} is the flux of π^- mesons; n is the effective number of nuclei in the target; t is the exposure time; d is the thickness of the emulsion; $[dE/dR]_E$ is the energy loss in the emulsion by π^+ mesons with energy E ([5]); η is the efficiency of recording $(\pi - \mu)$ decays by the photographic emulsion; (S/r^2) is the mean solid angle within which the stopped π^+ mesons are recorded.

The cross section calculated from the formula given above for an energy $E = 40$ MeV at an angle of 90° to the direction of the π^--meson beam is

$$\frac{d^2\sigma}{dE\,d\omega} = (2.6 \pm 1.3) \cdot 10^{-30}\ \text{cm}^2\ \text{sterad}^{-1}\ \text{MeV}^{-1}.$$

The indicated error in the measurement of the cross section includes the statistical error, as well as errors in determining the intensity of the π^--meson beam and the geometrical factors.

Since the spectrum of the π^+-mesons produced is unknown, and it was not possible to determine it with sufficient accuracy by means of the method described above, a spectrum calculated on the basis of perturbation theory ([6]) was used for the further calculations. It is true that in the present case perturbation theory is not applicable, but arbitrariness in the choice of the spectrum has little effect on the results within the indicated accuracy of the measurements.

Integration over the spectrum gives the cross section for the production of π^+-mesons by π^--mesons at an angle of 90°, equal to

$$\left(\frac{d\sigma}{d\omega}\right)_{90^\circ} = (2.1 \pm 1.1) \cdot 10^{-28} \text{ cm}^2 \text{ sterad}^{-1}.$$

On the assumption that the angular distribution of the π^+-mesons is isotropic, the total cross section for meson production by mesons on carbon nuclei is found to be

$$\sigma_C = (2.6 \pm 1.3) \cdot 10^{-27} \text{ cm}^2.$$

It should be noted that the π^+-mesons recorded by the photographic emulsion could have been produced not only by π^--mesons, but also by neutrons with an energy sufficient for meson production (~ 300 MeV). The admixture of neutrons in the beam was determined from the number of "neutron"stars (i.e., stars having no track of an incoming meson)* in the electron-sensitive emulsion placed inside the collimator, and was found to be 10%. It must be taken into account that the collimator is set in the direction of the center of the circulating proton beam in the synchrocyclotron chamber, and therefore the overwhelming majority of the neutrons entering it have an energy insufficient for π-meson production. If one uses the data on meson production by neutrons ([7]), one may conclude that in our case the contribution of neutrons to the production of π^+-mesons is very small and may be neglected.

Knowing the magnitude of the total cross section for meson production by mesons and assuming that the production of π^+-mesons in the nucleus can occur only on protons in accordance with the reaction $\pi^- + p \to \pi^+ + \pi^- + n$, one may attempt to estimate the cross section for the production of π^+-mesons on a nucleon. Difficulties arise, however, in determining the absorption coefficient of the meson in the same nucleus in which it was produced. A rough estimate, made on the basis of data on meson ranges in nuclear matter, leads to the conclusion that in the present case approximately 50% of the mesons produced in the carbon nucleus are absorbed. Then the cross section for the production of π^+-mesons by negative π-mesons on a nucleon is obtained as $\sigma_{\pi^- \to \pi^+} \sim 10^{-27}$ cm^2.

This value may be compared with the data of work ([2]), which gives an estimate of the cross section for the production of charged mesons by π^--mesons with an energy of 500 MeV on a nucleon. The authors conclude that the magnitude of the cross section at this energy lies within the range $3.5 \div 10.0$ mb.

The experimental scheme described above is intended to be used further in investigating the production of π^+-mesons by π^--mesons on liquid hydrogen. In this connection it is essential that the identification of only the π^+-meson already determines in this case the reaction $\pi^- + p \to \pi^+ + \pi^- + n$.

* In this estimate, the star-formation cross sections for neutrons and π-mesons were taken to be equal.

The results obtained allow us to conclude that, in setting up experiments on the elastic scattering of π^- mesons by hydrogen (using scintillation counters), even at an energy of 300 MeV it is necessary to take inelastic processes into account.

In conclusion we express our deep gratitude to B. Pontecorvo for directing the work and for constant assistance, and to E. L. Grigor' ev and V. M. Sidorov for discussion of the results and a number of valuable suggestions. We are also very grateful to N. N. Antonova for the great assistance rendered in examining the plates.

Institute of Nuclear Problems
Academy of Sciences of the USSR

Received
5 VI 1956

References

1. W. F. Fry, Phys. Rev., **91**, 1576 (1953).
2. M. Blau, M. Caulton, Phys. Rev., **96**, 150 (1954).
3. N. A. Mitin, E. L. Grigor' ev, DAN, **103**, 219 (1955).
4. A. E. Ignatenko, V. V. Krivitskii, A. I. Mukhin, B. Pontecorvo, A. A. Reut, K. I. Tarakanov, *Atomic Energy*, No. 5, 5 (1956).
5. N. Bradner, F. M. Smith, W. H. Barkas, A. S. Bishop, Phys. Rev., **77**, 462 (1950).
6. L. I. Lapidus, Dissertation, Institute of Nuclear Problems, Academy of Sciences of the USSR, 1953.
7. V. M. Sidorov, ZhETF, **28**, 727 (1955).

Note: Figure translations are in progress. See original paper for figures.