THE ELASTIC SCATTERING OF 307 MEV π^--MESONS FROM HYDROGEN

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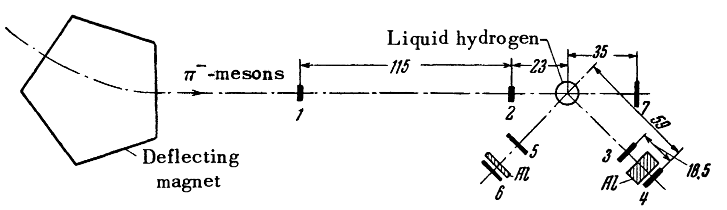
Scintillation counters were used to study the angular distribution of π^--mesons scattered elastically from hydrogen. The energy of the incident π^--mesons was 307 ± 9 Mev. The angular distribution obtained is closely represented by $d\sigma/d\omega = (0.56 + 0.42 \cos\vartheta + 1.1 \cos^2\vartheta) \times 10^{-27}$ cm^2 $sterad^{-1}$ in the center of mass system. A phase-shift analysis was carried out, using only S and P waves. Comparison of the data with the dispersion relations leads to the conclusion that the coupling constant f^2 for the meson-nucleon interaction is about 0.08.

TILL recently, the angular distribution of π^--mesons scattered elastically from hydrogen has been studied in detail only at energies below 220 Mev. The data on this interaction at ~ 300 Mev obtained with π^--mesons from the synchrocyclotron of the Joint Institute for Nuclear Research[1,2] have low statistical accuracy. In the present work, the angular distribution of π^--mesons from the process $\pi^- + p \rightarrow \pi^- + p$ was measured using scintillation counters.

Mesons were obtained from a beryllium target inside the synchrocyclotron of the Joint Institute for Nuclear Research. Upon passing through a collimator in the magnet yoke, they were bent by a focusing magnet and fell on a hydrogen target. The energy of the π^--mesons was 307 ± 9 Mev, and the beam intensity about 100 mesons/cm^2 sec.

The geometry of the experiment is shown in the figure. The beam incident on the hydrogen target was detected by counters 1 and 2, 6 × 6 cm in size and connected in coincidence. The scattered mesons were counted at two angles simultaneously by the two telescopes, each of which consisted of two liquid scintillation counters (3, 4 and 5, 6) 12.6 × 11.5 cm in size. The pulses from the photomultipliers were first shaped and then transmitted on high-frequency cables to a multi-channel coincidence circuit with a resolving time of ~ 1.2×10^{-8} sec. This circuit used germanium detectors and had a sensitivity ~ 0.5 volts. The number of double coincidences D from detectors 1 and 2 were registered on a scaler with resolving time ~ 10^{-7} sec. Fourfold coincidence Q from the counters 1, 2, 3, 4 and 1, 2, 5, 6, were passed through a gate operated by counter 7, which was in anti-coincidence with counters 1 and 2, and then registered mechanically. The anti-coincidence counter 7 was necessary to reduce the background of accidental coincidences. The anti-coincidence circuit used germanium detectors and had a resolving time of ~ 2.2×10^{-8} sec.



Geometry of the experiment. 1, 2 — scintillation counters, 6 × 6; 3, 4, 5, 6 — scintillation counters, 12.6 × 11.5; 7 — anti-coincidence counters, 12.6 × 11.5 cm.

The target was liquid hydrogen in a polystyrene foam bottle. There was about 0.735 g/cm^2 of hydrogen in the path of the beam, while the amount of material in the target was 0.35 g/cm^2. Measurements were made at angles of 30, 45, 60, 80, 100, 125, and 152 degrees in the laboratory frame of reference. During the measurements at 30, 45, and 60 degrees, counters 4 and 6 were shielded by 28.4, 20.2, and 9.4 g/cm^2 respectively of aluminum to absorb recoil protons. At the other angles, counters 4 and 6 were shielded by 5.4 g/cm^2 of aluminum to absorb protons from stars.

The differential cross section was computed from the formula

$$\left(\frac{d\sigma}{d\omega}\right)_{\text{lab}} = \frac{(Q/D)_{\text{with H}} - (Q/D)_{\text{without H}}}{kN\omega}$$

where $N = 0.443 \times 10^{24}$ is the number of hydrogen atoms per cm^2, and ω is the solid angle defined by the telescopes. k is a correction factor which takes account of the decrease in the telescope efficiency due to the aluminum filters, the increase in counting rate due to the conversion in counters 3 and 5 of γ-rays from π^0-decay, μ-meson contamination of the beam, meson absorption in the target walls and in counters 3 and 5, counting losses at high counting rates, and a number of other small corrections.

Measurements to be reported on spearately showed that at π^--meson energies of 307 Mev, meson production by mesons is appreciable. At an angle of 80° in the laboratory frame, the number of mesons produced in the hydrogen is about 7% of the number of elastically scattered π^--mesons. In correcting for this effect at other angles, the following assumptions were made: in the center-of-mass system, all the kinetic energy is carried away by the π-mesons, the mesons have a triagnular energy spectrum, and their angular distribution is isotropic.

TABLE I. Angular distribution of π^--mesons elastically scattered from hydrogen, $E_{\pi^-} = 307 \pm 9$ Mev.

Angle, c.m.s.	Differential cross section in 10^{-27} cm^2/sterad.	Angle, c.m.s.	Differential cross section in 10^{-27} cm^2/sterad.
41°20′	1.30 ± 0.27	118°59′	0.61 ± 0.07
60°35′	1.05 ± 0.13	140°01′	0.89 ± 0.1
78°28′	0.75 ± 0.09	160°16′	1.12 ± 0.12
99°57′	0.49 ± 0.06	—	—

Table I shows the values obtained for the differential cross section in the center-of-mass system after all corrections have been made. The errors shown are standard deviations, except for that at 41°. The results of repeated measurements at 41° differed among each other by more than the statistical error. The error quoted for this angle is the mean square error of a single measurement.

A least squares fit of the data to the expression

$$(d\sigma / d\omega)_{\text{c.m.s.}} = a + b\cos\vartheta + c\cos^2\vartheta \tag{1}$$

leads to the following values for the coefficients (in 10^{-27} cm^2 $sterad^{-1}$):

$$a = 0.56 \pm 0.05;\ b = 0.42 \pm 0.11;\ c = 1.1 \pm 0.16. \tag{2}$$

Upon integrating the expression (1), the integral cross section for the process $\pi^- + p \rightarrow \pi^- + p$, $\sigma_{\pi^- \rightarrow \pi^-}$, is found to be $(11.3 \pm 0.9) \times 10^{-27}$ cm^2. In Refs. 1 and 2 this cross section was found to be $(11 \pm 2) \times 10^{-27}$ cm^2 and $(11 \pm 4) \times 10^{-27}$ cm^2 respectively.

A preliminary phase-shift analysis has been carried out on the basis of the following simplifying assumptions: (1) only S and P waves need be considered and (2) the relation between the phase shifts and the angular distribution of elastically scattered π^--mesons at ~ 300 Mev is the same as it would be if there were no inelastic processes. The phase shifts describing the interaction in S, $P_{1/2}$, and $P_{3/2}$ states with isotopic spin $3/2$ are denoted by α_3, α_{31}, and α_{33}. These phase shifts were taken from Ref. 3. They are $\alpha_3 = -23.2°$, $\alpha_{31} = -8.4°$, and $\alpha_{33} = 133.2°$. The phase shifts describing the interaction in S, $P_{1/2}$, and $P_{3/2}$ states with isotopic spin $1/2$, are denoted by α_1, α_{11}, and α_{13}. Four sets of phase shifts were found, each minimizing the expression

TABLE II. Phase Shifts

α_1	α_{11}	α_{13}	M
5°	8°	−8.2°	1.4
1.5°	−22°	18°	1.5
15°	−19.5°	19.5°	1.3
11.8°	35.5°	7°	1.3

$$M = \sum_1^7 (\Delta_i / \varepsilon_i)^2,$$

where Δ_i is the difference between the experimentally observed differential cross section at a given angle and the value computed from the phase shifts, while ϵ_i is the experimental error in the measured differential cross section. The phase shifts and the corresponding value of M are shown in Table II.

It should be noted that although these sets of phase shifts all describe the angular distribution of elastically scattered π^--mesons equally well (M ~ 1.5, with an expected value of 4), none of them describe the angular distribution of π^0-mesons adequately. (The latter has been obtained in preliminary experiments.) The reason for this may appear after some supplementary measurements on exchange of scattering have been carried out, and a more detailed phase shift analysis, taking D waves into account, has been made. From a theoretical point of view, it is also not clear whether we are justified in neglecting the inelastic processes or not.

Measurements on the elastic scattering of π^--mesons can be used to obtain information on the coupling constant f between mesons and nucleons. It is well known[4] that dispersion relations give the energy dependence of the real part $D_-(0)$ of the π^--meson scattering amplitude at 0°. The curve depends on the value of f^2. Puppi and Stanghellini[5] pointed out that the experimental data for π^--mesons with energies less than 180 Mev leads to $f^2 \sim 0.04$, while the data for π^--meson energies $\sim$ 220 Mev lead to $f^2 \sim 0.08$. The experiments on the interaction of π^+-mesons with protons at energies up to 400 Mev lead to $f^2 \sim 0.08 - 0.1$. The relation between $D_-(0)$ and the coefficients in (1) is

$$|D_-(0)| = \sqrt{(a+b+c) - (k\sigma_t/4\pi)^2},$$

where σ_t is the total cross section for the interaction of π^--mesons with hydrogen,* and k is the wave number of the π^--meson.

The value obtained in this way for $D_-(0)$ is $D_-(0) = (-0.24 \pm 0.05) \times 10^{-13}$ cm at 307 Mev and is in satisfactory agreement with the curve corresponding to $f^2 = 0.08$.[5,6] This confirms the contradiction found by Puppi and Stanghellini. As these authors assume, the discrepancy with the results using π^--mesons with energies less than 180 Mev can be explained by electromagnetic effects and the $\pi^\pm - \pi^0$ mass difference.

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*The value $\sigma_t = (31.6 \pm 1.6) \times 10^{-27}$ cm^2 was obtained by interpolating the data of Ref. 7.