Total Cross Sections for Negative Pions on Protons at 230, 290, 370, 427, and 460 Mev*

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(Received November 21, 1960)

Total cross sections for negative pions on protons were measured at laboratory energies of 230, 290, 370, 427, and 460 Mev. The measurements were made in the same pion beams as and at energies identical with those of our π^--p differential scattering experiments. Comparisons of the total and differential scattering can be made with the dispersion theory at a given energy without introducing the systematic errors that would normally enter due to uncertainties in the parameters of more than one pion beam. The measured total cross sections are found to agree within statistics with other measured values, and with the sums of elastic, inelastic, and charge-exchange cross sections measured at this laboratory. The results are:

E(Mev)	σ_{total}(mb)	E(Mev)	σ_{total}(mb)
230±6	58±9	427±10	27±2
290±7	33±2	460±20	28±2
370±9	27±2		

I. INTRODUCTION

MANY measurements of the π^--p total cross section have been made in the energy region from 230 to 460 Mev.[1–3] The purpose of this experiment was to measure these cross sections in the same pion beams and at pion energies identical with those used in other π^--p differential-scattering experiments at this laboratory.[4–6] These total cross sections then can be checked against the sum of the integrated differential cross sections. They also can be used with the differential data at 0 deg to check the predictions of dispersion theory. The advantage of measuring total cross sections in this manner is that we avoid those systematic errors that arise from determining pion-beam parameters separately for the total and differential scattering data.

The total-cross-section data were taken by measuring the total attenuation of pions in a long liquid-hydrogen target. A calculated Coulomb-scattering correction was subtracted.

II. EXPERIMENTAL METHOD

The experimental arrangement is shown in Fig. 1. The negative pion beam was produced by the internal proton beam of the Berkeley 184-in. synchrocyclotron striking a Be target. The pion-beam energies and muon contaminations, listed in Table I, were determined by range measurements in copper. The electron contaminations of the beams were measured at the two lower energies with a gas Cherenkov counter, and were calculated at the three higher energies.

The liquid-hydrogen target was 4 ft long, and the counters were plastic scintillators. A schematic diagram of the electronics circuit is shown in Fig. 2. Details of the apparatus are discussed elsewhere.[4–8]

III. RESULTS

A. Beam Attenuation

In order to obtain a value for the true total-attenuation cross section, the total attenuation of the pion beam was measured at a number of small forward solid

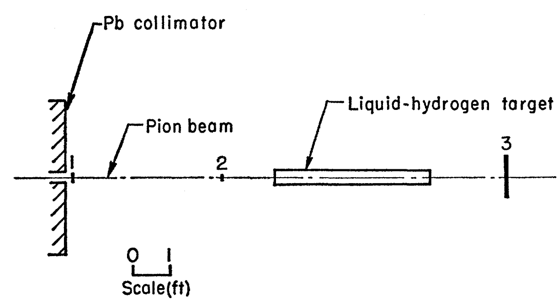

FIG. 1. The experimental arrangement.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
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angles at each energy and these values were extrapolated to $\Omega=0$. The fraction of the beam particles transmitted through the target was determined by recording triple coincidences (123) and double coincidences (12) for each incident pion energy and at each of several distances between counter 3 and the

TABLE I. Negative-pion-beam energies and contaminations.

Pion beam energy, lab (Mev)	Muon contamination (%)	Electron contamination (%)
230±6	15±1	5±1
290±7	8±1	1±1
370±9	4±1	1±1
427±10	4±1	1±1
460±20	4±1	1±1

target (see Fig. 1). With due consideration for the electron and muon contamination present in the beam, the pion-attenuation cross section, $\sigma'(\Omega)$, was then calculated as a function of Ω, the mean solid angle subtended by counter 3 at each distance d (obtained by a suitable average over the length of the target).

B. Total Cross Sections

The "apparent" total cross section is given by the difference between the measured pion total attenuation

TABLE II. Forward cross sections at various solid angles.

Beam energy (Mev)	Ω (sr)	σ' (mb)	σ_c (mb)	σ (mb)
230	0.021	52.7±7.9	0.6	52.1±7.9
	0.015	54.6±8.0	0.8	53.8±8.0
	0.010	56.2±8.1	1.1	55.1±8.1
	0.007	60.8±9.0	1.6	59.2±9.0
290	0.021	30.5±1.3	0.4	30.1±1.3
	0.015	31.2±1.3	0.5	30.7±1.3
	0.010	34.3±1.3	0.7	33.6±1.3
	0.007	33.0±1.3	1.1	31.9±1.3
370	0.080	24.7±1.1	0.1	24.6±1.1
	0.062	25.1±1.2	0.1	25.0±1.2
	0.044	25.0±1.2	0.1	24.9±1.2
	0.028	26.3±1.2	0.2	26.1±1.2
	0.019	27.6±1.2	0.3	27.3±1.2
427	0.080	25.9±1.2	0.1	25.8±1.2
	0.062	25.9±1.2	0.1	25.8±1.2
	0.044	26.3±1.2	0.1	26.2±1.2
	0.028	27.2±1.2	0.1	27.1±1.2
460	0.080	26.3±1.2	0.1	26.2±1.2
	0.062	27.0±1.1	0.1	26.9±1.1
	0.044	27.4±1.2	0.1	27.3±1.2

and the calculated Coulomb-scattering cross sections for each value of Ω. The calculated average Coulomb cross section at each point, $\sigma_c(\Omega)$ is listed in Table II, with the measured and corrected cross sections, where σ is assumed to be purely nuclear. Interference between nuclear and Coulomb scattering can be neglected.

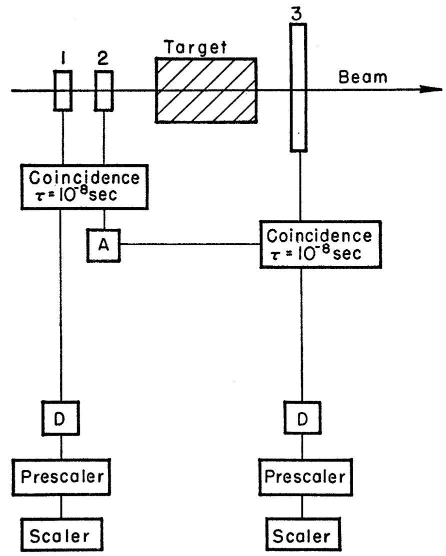

FIG. 2. Schematic diagram of the electronics.

The corrected cross sections were extrapolated to zero solid angle at each energy by fitting the following form to the data points:

$$\sigma(\Omega)=A+B(\Omega)^2.$$

This parabolic extrapolation function was chosen because it is simple and has the desired property of zero slope at $\Omega=0$. The curves obtained are shown in Fig. 3, and the total cross sections obtained from the

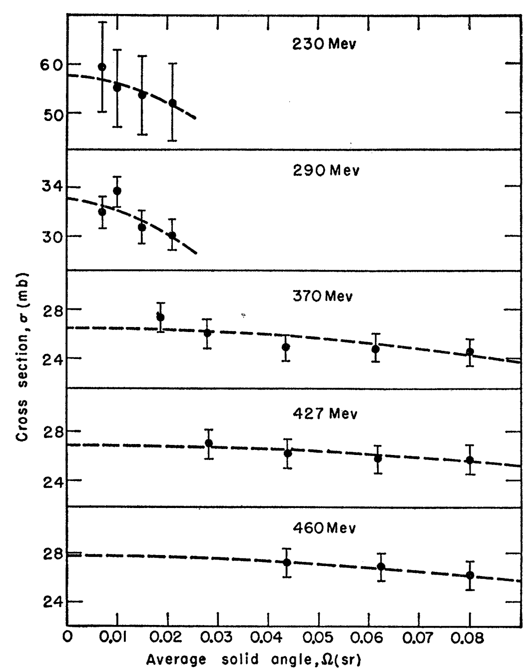

FIG. 3. Extrapolation curves for the total cross sections σ_t.

TABLE III. Total π^--p cross sections.

Beam energy (Mev)	Total cross section σ_t (mb)	Total elastic cross section (mb)	Total charge-exchange cross section (mb)	Total charged inelastic cross section (mb)	Σ,[a] total cross section (mb)
230	58±9	20.8±0.4[b]	30.4±1.3[c]	0.3±0.3[d]	51.5±1.4
290	33±2	13.8±0.3[b]	18.2±0.8[c]	2.4±0.8[b]	34.4±1.2
370	27±2	10.9±0.2[b]	13.6±0.6[c]	3.1±0.8[b]	27.6±1.0
427	27±2	13.0±0.4[b]	10.3±2.3[a]	3.7±1.0[b]	...
460	28±2	...	...	...	...

[a] Calculated.
[b] Goodwin (reference 4).
[c] Caris *et al.* (reference 5).
[d] Perkins *et al.* (reference 6).

extrapolation σ_t are listed in Table III for each pion energy.

C. Errors

Errors in this experiment are due to the statistics of counting and the uncertainties in muon and electron contaminations in the pion beam. The latter error occurs particularly in the 230-Mev beam; at higher energies the contaminations are much smaller and less important. The uncertainties due to electron contamination enter not only as errors in measuring their total numbers but also in the way that they scatter in the target, either missing or traversing counter 3 (depending strongly upon their energy).

The energy spectrum of the electron contamination was not measured. The contamination is composed of electrons having momentum equal to the pion-beam momentum, as well as a low-energy tail. Low-momentum electrons are Coulomb-scattered enough so that almost 100% of them miss counter 3. Electrons in the high-momentum peak are scattered so little that almost none of them miss counter 3. Without an energy distribution of the electron contamination, the electron scattering cannot be evaluated accurately. The Cherenkov counter used to measure only the total flux of electrons had an electron-energy threshold of about 10 Mev. Consequently, the electron-contamination correction was treated by assuming, first that all electrons scattered so that they missed counter 3, and second, that none of them missed counter 3. The cross sections obtained from these two limits were averaged, and the error assigned to them taken as half their difference. These errors on σ' are given in Table II.

Errors arising from counting statistics and from Coulomb scattering of pions and muons were calculated and are included in the errors assigned to the final total cross section σ_t. The uncertainties in the target parameters are also included in the final cross sections.

IV. CONCLUSIONS

The total π^--p cross sections found are in statistical agreement with previously measured values.[2,3] They can also be compared with cross sections calculated from π^--p elastic, charge-exchange, and inelastic cross sections at energies where these values are known. Measured values of the elastic π^--p total cross sections are available at the four lowest energies.[4] Comparable data on the measured charge-exchange total cross sections are available at the three lowest energies.[5] The inelastic cross section for the interaction $\pi^-+p \rightarrow \pi^+ +\pi^-+n$ has been measured previously,[6] and information is available for the total charged inelastic cross sections at 290, 370, and 427 Mev.[4] These data are given in Table III. The sum of these cross sections, where known, is also given in Table III, and the values obtained agree within statistical limits with the total cross sections measured in this experiment. At 427 Mev, the available data were used to calculate a value for the charge-exchange cross section. In these calculations, the contribution from the interaction $\pi^-+p\rightarrow\pi^0 +\pi^0+n$ is not included. From agreement obtained in these compilations it can be assumed that this cross section cannot be more than a few millibarns. These results are compared by Goodwin[4] with values of $d\sigma/d\Omega$ (0 deg) in a discussion of dispersion theory.

ACKNOWLEDGMENTS

Thanks are due James Vale and the cyclotron crew for their assistance and cooperation during the course of the experimental work, and to the hydrogen-target group for installing the hydrogen target.