BIOTHEQUE

CM-P00055856

TRI-PP-83-14
Mar 1983

True absorption and scattering of 50 MeV pions

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Abstract

The inclusive pion inelastic scattering and true absorption cross sections at 50 MeV were measured for π^+ on natural Li, C, Fe, Nb, Bi and for π^- on C, Fe, Bi. The results show that π^- cross sections are much larger than π^+ , the difference being significantly larger than expected from a simple Coulomb calculation. In particular, in ^{12}C the absorption of negative pions is about twice that of positive pions.

(submitted to Physics Review C Rapid Communications)

In a previous series of experiments carried out at SIN, the inclusive cross sections for true absorption and scattering of pions were measured¹⁻³ on nuclei from Li to Bi at bombarding energies from 85 to 315 MeV. The agreement between the data and theoretical calculations that used pionic atom parameters⁴ was not very good, probably due to the difficulty in extrapolating from zero to high energies. We focus now on lower energies to see whether the absorption process exhibits different features away from the (3-3) resonance, and to have more meaningful comparison with the calculations based on zero energy parameters. It is expected that absorption data at low energy might also help to narrow down the ambiguities in the parameters of the reactive part of the optical potential, since they are not uniquely determined by existing data of pionic atoms.⁵

We measured the absorption and inclusive scattering cross section of 50 MeV positive pions on Li, C, Fe, Nb, and Bi and of negative pions on C, Fe, and Bi. The experimental method was the same as used previously,¹⁻³ and will be reviewed here only briefly.

In order to obtain the true absorption cross sections, two separate experiments had to be performed and their results combined together. Both experiments were carried out at the TRIUMF laboratory, in the M9 and M13 channels. The targets were squares 40x40 mm, and their thicknesses were 0.29, 0.45, 1.27, 1.67, 1.01 g/cm² for Li, C, Fe, Nb, and Bi, respectively.

The first experiment was done using a standard transmission technique of the kind used for measurements of total cross sections. The pion beam hit the target after passing through two plastic scintillators used to monitor the beam flux. Muon and electron contaminations were measured by time of flight. Two 3 mm thick plastic scintillation

counters of disc shape and diameters of 38 and 34 cm were placed on the beam axis behind the target. The counters were placed in four different positions so that they covered eight solid angles in the range 0.46-1.28 sr. A disc counter that subtends a solid angle Ω from the target serves to measure $\sigma_{\text{tr}}(\Omega)$, defined as the cross section for removing pions from the incident flux without rescattering a charged pion into the solid angle Ω . This is done by measuring the small fraction of the incident beam that no longer hits the disc counter when the target is inserted. The transmission cross section $\sigma_{\text{tr}}(\Omega)$ is given by:

$$\sigma_{\text{tr}}(\Omega) = \frac{1}{n_t} \lambda_n \frac{N(0)}{N(t)} = \sigma_{\text{abs}} + \sigma_{\text{cx}} + \int_{\Omega} \frac{d\sigma_{\text{sc}}}{d\Omega} d\Omega, \quad (1)$$

where n_t is the number of target nuclei, and $N(t)$ and $N(0)$ are the number of counts in the detector with and without target in the beam, respectively; σ_{abs} is the absorption cross section, σ_{cx} is the single charge exchange cross section, and σ_{sc} is the charged pion scattering cross section which includes elastic scattering, inelastic scattering to all final states, and double charge exchange reactions. The integration of the differential cross section is taken over the angle Ω , complementary to the solid angle Ω subtended by the disc detector.

In the second experiment the differential scattering cross section was measured. Beam monitoring and contamination measurement were done as in the transmission experiment. The scattered pions were measured by three plastic scintillator telescopes, separated by 10° . Each consisted of a thin ΔE (27x27x5 mm) and a thick E (50x50x50 mm) detector, placed at distances of 30 and 40 cm, respectively, from the centre of the target. With these telescopes it was possible to identify pions and resolve them from other charged particles.

From the number of scattered pions detected at each angle the inclusive differential cross section (regardless of the scattered pion energy) was obtained in the angular range 25° - 150° . The angular distributions for scattering of positive and negative pions from ^{12}C are given in Fig. 1. The errors in the data points of the distribution vary between 4% and 10% including the statistical and angle-dependent systematic errors. The estimated overall normalization uncertainty is 12%.

The measured angular distributions were integrated over the solid angles defined in Eq. (1) and the results of the integrations were subtracted from $\sigma_{\text{tr}}(\Omega)$. The differences are equal to $\sigma_{\text{abs}} + \sigma_{\text{cx}}$ [see Eq.(1)], and are listed in Table I. The errors include contributions from statistics, systematic errors, and errors introduced by this subtraction procedure. More detailed discussion of this procedure and several examples are given in Ref. 3. In order to obtain the true absorption cross section the contribution of the single charge exchange reaction σ_{cx} has to be subtracted. In the absence of complete experimental data, we used the results of Bowles et al. for $^{16}\text{O}(\pi^+, \pi^0)$ at 50 MeV,⁶ and extrapolated them to other targets using the A dependence deduced from the (π^-, π^0) measurement at 70 MeV.⁷ In this crude approximation we used the same charge exchange cross sections for π^+ and π^- , and the errors were set arbitrarily to 30%. Since these cross sections are relatively small, as can be seen in Table I, the error that they introduce to the absorption cross sections is small.

The most pronounced feature of the absorption cross sections is the large values obtained for π^- : in ^{209}Bi it is more than 5 b and is the dominant part in the total cross section.⁸ The most striking difference

between absorption of positive and negative pions is in ^{12}C . Simple calculations of the Coulomb contribution to the ratio, using $(1+E_b/T)/(1-E_b/T)$, where E_b is the Coulomb barrier energy and T is the pion kinetic energy, yield a difference of only about 20%, not a factor of 2.

The unexpected large ratio led us to a careful comparison of our raw data with other existing experimental results. The transmission data for ^{12}C was compared with the LAMPF data of Cooper et al.⁹ and was found to be in excellent agreement (within 4%). The inclusive scattering differential cross section (Fig. 1) was compared with elastic scattering data of π^+ , $^{10-12}$ and π^- .^{13,14} Unfortunately, these measurements of elastic scattering cross sections disagree with one another. The inclusive scattering cross sections measured in the present experiment are, as they should be, larger than the corresponding elastic cross sections, with the exception of Ref. 13. This reference also disagrees with Ref. 14 and a recent measurement performed at TRIUMF¹⁵ indicates that it might have been incorrect. It should be noted, however, that even if the results of Ref. 13 are correct, our conclusions about the absorption cross sections will not change by more than 15%. Summing up all our checks, we are confident that the big ratio is a genuine effect.

In Fig. 2 we plot the experimental results together with theoretical predictions.^{4,16} As can be seen the data exhibit a smooth dependence on the atomic number. The agreement between the calculations and the data is only fair. The absorption cross section at low energies was also deduced by Nakai et al.¹⁷ from measurements of γ multiplicities. The indirect character of that measurement makes the comparison less conclusive, but their ratios between π^- and π^+ seem to be significantly smaller. It is interesting to note that fits to the elastic data,¹⁸

using a simple well potential, gave a reactive cross section similar to that observed in this experiment with the same large ratio between π^+ and π^- . (The reactive cross section in this energy is dominated by true absorption because the integrated inelastic scattering is relatively small.) No simple explanation was found for the big ratio seen in ^{12}C . Perhaps the relatively complex nature of the absorption process in which more than one nucleon is usually involved makes the simple Coulomb approximation invalid.

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TABLE I. Cross sections for π^+ and π^- (mb).

target	$\sigma_{abs} + \sigma_{cx}$	σ_{cx}^a	σ_{abs}
π^+			
Li	40 ± 17	12	28 ± 21
C	106 ± 21	18	88 ± 27
Fe	478 ± 48	35	443 ± 58
Nb	782 ± 95	40	742 ± 107
Bi	1737 ± 188	49	1688 ± 203
π^-			
C	238 ± 24	18	220 ± 30
Fe	1232 ± 92	35	1197 ± 102
Bi	5137 ± 328	49	5088 ± 343

^aEstimated, see text.

Figure captions

1. Angular distributions for scattering of π^+ and π^- from ^{12}C at 50 MeV. Only the statistical errors are shown.
2. Calculations (Refs. 4,16) and experimental results of this work for absorption of π^+ and π^- at 50 MeV. The lines were drawn through the experimental results to guide the eye.

Fig. 1

Fig. 2