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CHARGE EXCHANGE OF 70 MeV π^- ON C, Al, Cu AND Pb

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Abstract: The integrated cross sections for the total charge exchange of 70 MeV π^- on natural carbon, aluminium, copper and lead have been measured by detecting the π^0 decay γ-rays. For lead, the cross section per proton was found to be about 12 times smaller than for a free proton. The dependence of the cross section per proton on the mass number A is compared with theoretical predictions and a value for the cross section of the elementary pion-nucleon interaction inside the nucleus is derived.

E | NUCLEAR REACTIONS C, Al, Cu, Pb(π^-, π^0), E = 70 MeV; measured σ.

1. Introduction

It is well known that the cross section per nucleon in pion-nucleus scattering decreases with increasing mass number A if the mean free path of the incident pion in nuclear matter is comparable with the nuclear radius. This effect can be taken into account by introducing a reduction factor R which was calculated by Ericson *et al.* [1]) using the impulse approximation and the Fermi gas model. The reduction factor R depends on two parameters, the nuclear mass or charge density distribution and a cross section $\sigma_{\pi N}^A$ for the elementary pion-nucleon interaction within the nucleus. Up to now, it was uncertain which value to use for $\sigma_{\pi N}^A$. Two possibilities were mainly discussed: the total πN cross section with some contribution from pion pair absorption [2]) and the cross section for inelastic processes only [1]).

A measurement of R in nuclei with a known mass distribution allows a determination of $\sigma_{\pi N}^A$ under certain assumptions. We have determined R by means of the charge exchange reaction $\pi^- + A_Z^N \rightarrow \pi^0 + X$ of 70 MeV π^- on natural carbon, aluminium, copper and lead. The reaction was identified by detecting the π^0 decay γ-rays. The R-values obtained for carbon and lead were then used to derive $\sigma_{\pi N}^A$.

2. Experimental procedure

The experimental arrangement is shown in fig. 1. The pion beam generated from an internal target of the 600 MeV CERN synchrocyclotron was defined by the plastic

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scintillator counters 1 and 3. A lucite total reflection Čerenkov counter 2 suppressed the electrons in the beam. The targets (10 cm × 10 cm disks) were inclined at 52.5° with respect to the beam and had an effective thickness corresponding to an energy loss of 5.6 MeV for the incoming π^-. In the target centre the pions had a mean energy of 70 MeV.

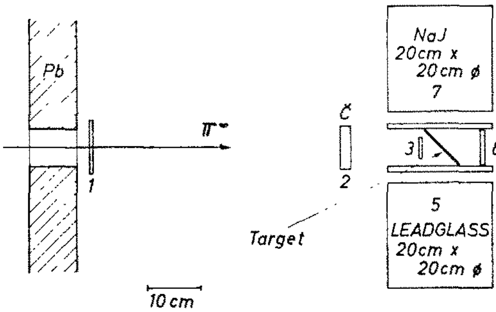

Fig. 1. Experimental arrangement. The charge exchange reaction is selected by the coincidence condition $(1\bar{2}3\bar{4}5\bar{6}7\bar{8})$.

The two π^0 decay γ-rays were detected by an NaI crystal and a lead-glass Čerenkov counter. Charge exchange was recorded as a coincidence $(1\bar{2}3\bar{4}5\bar{6}7\bar{8})$ between an incoming π^- and two γ-rays with the further condition that no charged particle left the target through counters 4, 6 or 8. The gamma counters were calibrated with the reaction $\pi^-_{\text{at rest}}+\text{p} \rightarrow \pi^0+\text{n}$ by stopping π^- in a CH_2 target. The background, essentially due to charge exchange in counter 3, was determined by a measurement without the target and amounted to about 23 % of the registered rate in the case of the carbon target.

The efficiency ε of the π^0 detection depends in our arrangement on the π^0 angular distribution and is therefore, in principle, dependent on the target nucleus. As our experiment gives no information on the angular distribution, we estimated this influence by a Monte Carlo calculation carried out for different angular distributions (free nucleon, isotropic, $\cos^2\theta$) with the two alternatives that the recoil is taken by one nucleon or by a nucleus with $A = 12$ (carbon). The efficiencies relative to the efficiency in the free nucleon case, obtained for 70 MeV π^-, are shown in table 1. The

TABLE 1

Calculated efficiencies relative to free nucleon case

	^{12}C recoil	Nucleon recoil
$c_1 = 4$, $c_2 = 5$, $c_3 = 2$, like free nucleon but forward peaked	1.00	0.73
$c_1 = 1$, $c_2 = c_3 = 0$ isotropic	1.08	0.89
$c_1 = c_2 = 0$, $c_3 = 1$ $\cos^2$	0.89	0.69

π^0 angular distribution: $c_1+c_2\cos\theta_{\text{c.m.}}+c_3\cos^2\theta_{\text{c.m.}}$: free nucleon case: $c_1 = 4.0$ $c_2 = -5.0$ $c_3 = 2.0$ [ref. [3])].

absolute efficiency was measured, using the reaction $\pi^- + p \rightarrow \pi^0 + n$ on free hydrogen, where the cross section at 70 MeV is known to be $\sigma_H = 8.8 \pm 0.5$ mb [ref. [3])]. In the measurement the difference in the coincidence rate for a CH_2 target and a C target was taken. The efficiency obtained was $\varepsilon = (2.6 \pm 0.4)$ %. Table 1 shows deviations in the efficiency up to 30 % from the free nucleon case. The cross sections quoted in table 2 use ε as determined from free protons. The errors given are the purely statistical errors and, in brackets, the errors containing a 30 % uncertainty in ε.

3. Results and discussion

The integrated cross sections $\sigma(\pi^-, \pi^0)$ are given in table 2. Fig. 2 shows the cross sections per proton versus the mass number A. The two curves in fig. 2 give the A-dependence of the cross section per proton as expected for a Gaussian nuclear charge distribution ($\sigma_H R_G$) and a constant charge density ($\sigma_H R_{cd}$) according to Ericson

TABLE 2

Integrated cross sections $\sigma(\pi^-, \pi^0)$ for total charge exchange in mb

C	Al	Cu	Pb
27.5±2.8(8.7)	39.5±3.7(12.4)	44.3±4.1(13.9)	58.7±5.7(18.5)

The errors given are the purely statistical errors, and, in brackets, the errors containing a 30 % contribution from the uncertainty in the π^0 detection efficiency (see text).

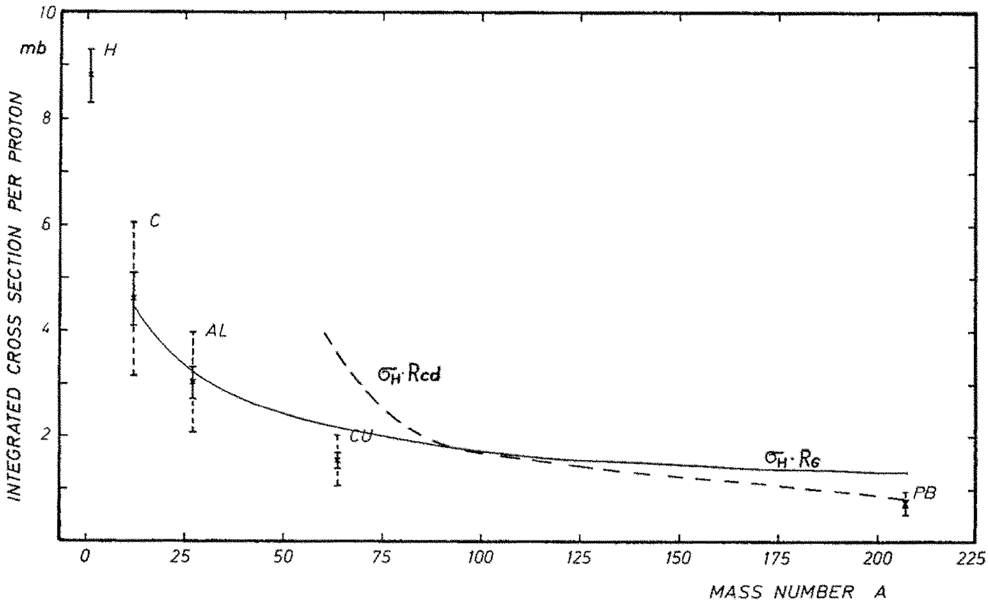

Fig. 2. Integrated total charge exchange cross section per proton versus mass number for 70 MeV π^-. The smaller error bars indicate statistical errors, the larger ones contain a 30 % uncertainty in the π^0 detection efficiency. The two curves are theoretical estimations (see text).

et al. [1]). They assumed the pion-nucleon cross sections $\sigma_{\pi N}$ to be the same for the incoming π^- and outgoing π^0 and obtained for a Gaussian distribution

$$R_G = \frac{2\pi\langle r^2\rangle}{3\sigma_{\pi N}^A A}$$

and for a constant density distribution

$$R_{cd} = \frac{\pi}{(\sigma_{\pi N}^A)^3 \omega_0^2 A},$$

where $\langle r^2\rangle$ is the mean square nuclear charge radius and ω_0 is the nuclear density.

For light nuclei like ^{12}C the Gaussian distribution should be a good approximation. Therefore $\sigma_{\pi N}^A$ was determined by comparing our experimental reduction factor $R_{exp}(^{12}C) = (\sigma_C/6\sigma_H)$ with R_G. With $\langle r^2\rangle = (2.42\pm0.04)^2$ fm^2 [ref. [4])] and $\sigma_H = 8.8\pm0.5$ mb [ref. [3])], the measured value of $R(^{12}C) = 0.52\pm0.06$ leads to $\sigma_{\pi N}^A = 19.6\pm2.4(6.3)$ mb. The error quoted contains the uncertainty in $\langle r^2\rangle$ and the statistical error in our measurement, the error in brackets contains also the uncertainty in the detection efficiency.

For higher mass numbers the nuclear density becomes more and more constant, and for lead a constant density is assumed to be a fair approximation. Comparing $R_{exp}(Pb) = (\sigma_{Pb}/82\sigma_H)$ with R_{cd}, we get $\sigma_{\pi N}^A = 21.0\pm1.1(2.4)$ mb using $r_0 = 1.19\pm0.02$ fm [ref. [4])]. The two values of $\sigma_{\pi N}^A$ are in surprisingly good agreement. For the normalization of the two curves in fig. 2, their unweighted mean $\sigma_{\pi N}^A = 20.3$ mb was used.

We compare now the values of $\sigma_{\pi N}^A$ with the two alternative assumptions made so far for this quantity: (i) total πN cross section plus pair absorption, (ii) cross section for the inelastic processes only, i.e. the same as (i) but neglecting elastic scattering.

At 70 MeV π^- energy, the total cross section on the free proton is 12.4 ± 0.3 mb [ref. [3])], on the free neutron 26 ± 4 mb [ref. [3])]. The latter value was taken from π^+p data which should be the same as for π^-n, for isospin reasons. The total cross section per nucleon would then be 19 mb for ^{12}C and 21 mb for Pb. These values are in remarkable agreement with our experimental finding for $\sigma_{\pi N}^A$, though pair absorption has not been taken into account. However, the existence of pair absorption is well established with a cross section comparable to the one for elastic scattering. We conclude therefore that assumption 1 gives too big a value for the parameter $\sigma_{\pi N}^A$.

To give a more quantitative argument we must make some assumption about the pair absorption cross section in nuclei, which has hitherto not been measured in our energy range except for the deuteron. Francis and Watson [5]) assumed that in nuclei the pair absorption cross section is 4 times higher than for the free deuteron, the factor 4 representing the greater chance of finding a nucleon pair close enough together for pion absorption inside the nucleus as compared to the deuteron. The expression for $\sigma_{\pi N}^A$ in the case of carbon would then be $\sigma_{\pi N}^A = \frac{1}{12}(6\sigma_{\pi^-p}+6\sigma_{\pi^-n}+9\cdot 4\sigma_{\pi^-d}^{abs})$. The factor 9 in front of the pair absorption cross section gives the number of possible nucleon pairs for π^- absorption; $\sigma^{abs}_{\pi^- d}$ was estimated to be 6 mb using the known experimental value of 7.0 ± 1.4 mb [ref. [6])] for 85 MeV π^- energy. With assumption (i), this formula gives $\sigma^{A}_{\pi N} = 37$ mb, with assumption (ii), where $\sigma_{\pi^- p} = 8.8 \pm 0.5$ mb [ref. [3])] and $\sigma_{\pi^- n} = 0$, we get $\sigma^{A}_{\pi N} = 22$ mb.

Assumption (ii) gives apparently a good agreement with our experimental result, while assumption (i) is obviously excluded. This seems to indicate that the elastic scattering is not of great influence for the reduction of the cross sections. In order to clarify the situation an experimental determination of the pair absorption cross section is needed.

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