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THE ($\pi^{\mp}$,πN) KNOCKOUT REACTIONS ON C^{12} FROM 30 TO 90 MEV

J. Alster, D. Ashery, S. Cochavi,

M.A. Moinester, A.I. Yavin and M. Zaider

Department of Physics and Astronomy

Tel-Aviv University, Ramat-Aviv, Israel

Abstract

The cross sections for the knockout reactions $C^{12}(\pi^-,\pi^-n)C^{11}$ and $C^{12}(\pi^+,\pi^+n+\pi^0p)C^{11}$ were measured over the energy range of 30 to 90 MeV by an activation method, and compared to existing calculations. In this energy range, the ratio $\sigma(\pi^-C^{12})/\sigma(\pi^+C^{12})$ of the cross sections is 2 to 3 times smaller than the corresponding ratio for pions on nucleons, contrary to the expectations of the impulse approximation. Such a behavior has previously been known only near the energy of the (3,3) resonance.

The knockout reactions of the type $A(\pi^{\mp},\pi N)B$ constitute a major component of the pion-nucleus reaction cross section[1,2]. These reactions have previously been studied[3-6] over the energy range of 50 to 1900 MeV. The excitation function of the reactions $C^{12}(\pi^{\mp},\pi N)C^{11}$ has a peak near the energy of the (3,3) resonance in the πN cross section[5,6]. This feature led to impulse approximation interpretations[1,5-9] of the knockout reaction based on the idea of quasi-free scattering of pions from individual nucleons within the nucleus.

In the plane wave impulse approximation (PWIA) calculation for the $A(\pi^{\mp},\pi N)B$ reaction in nuclei, the free πN reaction cross sections appear explicitly[1,6]. The ratio R(A) defined by

$$R(A) = \frac{\sigma\{A(\pi^-,\pi^-n)B\}}{\sigma\{A(\pi^+,\pi^+n+\pi^0p)B\}}$$

can then be compared to the corresponding ratio R(N) for free πN reactions, where[10]

$$R(N) = \frac{\sigma(\pi^-n \to \pi^-n)}{\sigma(\pi^+n \to \pi^+n+\pi^0p)} = \frac{9|f(3/2)|^2}{|f(3/2)+2f(1/2)|^2 + 2|f(3/2)-f(1/2)|^2} .$$

The symbol f(T) is the π-nucleon scattering amplitude for isospin T. By symmetry, one can replace $\sigma(\pi^{\mp}n)$ by available data[11,12] for $\sigma(\pi^{\pm}p)$. Around T_π = 180 MeV, the πp phase shifts[13,14] show almost no T=1/2 scattering compared to T=3/2, so that R(N) ≈ 3. A similar ratio is then expected for R(A).

Reeder and Markowitz[5] investigated the $C^{12}(\pi^-,\pi^-n)C^{11}$ reaction in the energy range of 50 to 1900 MeV by analyzing the β^+ activity of the residual nucleus C^{11}. Chivers et al[6] measured this activation cross section for $C^{12}(\pi^-,\pi^-n)C^{11}$ around 120 and 180 MeV, and for $C^{12}(\pi^+,\pi^+n+\pi^0p)C^{11}$ between 80 and 280 MeV ; *they found* $R(C^{12})$ *around* T_π *= 180 MeV to be equal to 1.0 ± 0.1* rather than the ratio of 3 predicted by the impulse approximation. Chivers et al[6] and Plendl et al[15,16] also studied the knockout reaction around T_π = 180 MeV for other targets. There have been no determination of R(A) at low pion energies.

Theoretical attempts have been made to explain the difference between the predicted and measured $R(C^{12})$ values at 180 MeV, as well as the shape of the excitation curve for $\sigma(\pi^- C^{12})$ up through the (3,3) resonance. Kolybasov[7] carried out a PWIA calculation, to which Selleri[9] added kinematic corrections. Balkarov[17] as well as Kolybasov and Smorodinskaya[18] modified the calculation of Kolybasov[7] by including higher order pion rescattering processes. In the above calculations[7,9,17,18] the magnitude was normalized to the experimental results around T_π = 180 MeV, but there are considerable differences in the shape of the excitation curve at lower energies. Bertini[8] considered effects of absorption and a diffuse nuclear surface within the framework of a Monte Carlo direct knockout calculation. Hewson[19] got improved agreement for $R(C^{12})$ at T_π = 180 MeV by including the effects of charge exchange in the final state interactions of the outgoing neutron with the residual nucleus. Robson[20] further investigated the final state interactions and found that R(A) is very sensitive to compound nucleus formation in the final state.

We report here measurements of the cross sections of the reactions $C^{12}(\pi^-,\pi^-n)C^{11}$ and $C^{12}(\pi^+,\pi^+n+\pi^0p)C^{11}$ in the energy range of 30 to 90 MeV. The secondary pion beam from the Saclay electron linear accelerator was used. The data were obtained by analysis of the 20.4 min β^+ activity of C^{11}, so that the cross section to the sum of all the bound states of C^{11} is obtained. Typical beam intensities on target were about 3×10^5 pions per second. The beam had an energy spread of $\pm10\%$, and also contained protons, positrons and muons. The protons were stopped by aluminum absorbers. We found that the positrons (and possible neutron background) caused no significant effect by carrying out measurements with a beam consisting mainly of positrons (obtained by stopping the pions in an absorber). No significant contribution to the cross section from the muons is expected. The pion beam was monitored by measuring the integrated electron current incident on the pion production target, and its intensity was determined from previously measured values of the pion yields[21]. Variations of beam intensity with time were monitored with a small plastic scintillator placed directly behind the target. This detector was also used to measure the beam profile for each energy. The C^{12} targets consisted of graphite disks, 3 cm in diameter, with thicknesses ranging from 0.8 to 4.0 gm/cm^2. Irradiations were carried out for a period of one to two half-lives of the C^{11} activity. The γ rays from the β^+ annihilation were measured in coincidence by two NaI(Tl) detectors in a shielded area. The decay curves were recorded in a multiscaler for a period of several half-lives, and all showed the characteristic 20.4 min. activity.

In Fig. 1 we present our experimental data along with the results of Reeder and Markowitz[5] and of Chivers et al[6], and compare them with the calculations of Bertini[8] and of Selleri[9]. Our results for $\sigma(\pi^+C^{12})$ at 70 and 90 MeV are consistent with the results of Chivers et al at 83 MeV. Our results for $\sigma(\pi^-C^{12})$ are consistent with those of Reeder and Markowitz, considereing their quoted uncertainties in the incident energies of about $\pm$8 MeV, except at 50 MeV. Comparing to theory, Bertini's calculation for $\sigma(\pi^-C^{12})$ is higher than the data but the shape is similar. Selleri's calculation of the shape for $\sigma(\pi^-C^{12})$ agrees with the data at all energies. For $\sigma(\pi^+C^{12})$, Bertini's calculation is in fair agreement with the data at low energies, but not at energies above 140 MeV.

The experimental ratios $R(C^{12})$ from our data and that of Chivers et al[6] are shown in Fig. 2. The ratios deduced from the pion-proton cross sections[11,12] and the calculation of Bertini for C^{12} are shown for comparison. Bertini's ratio is similar to the pion-proton ratio over the entire range shown. This can be expected[8] since the absorption factors for π^- and π^+ are approximately equal. We see that the ratio $R(C^{12})$ is considerably smaller than the corresponding R(N) (by a factor of 2 to 3), not only at T_π = 180 MeV, where this has previously been known[6], but at lower energies as well.

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Figure Captions

Fig. 1 : Activation cross sections for the $C^{12}(\pi^-,\pi^- n)C^{11}$ and $C^{12}(\pi^+,\pi^+ n+\pi^o p)C^{11}$ knockout reactions as a function of pion energy. The present data, along with the data of Reeder and Markowitz[5] and of Chivers et al[6] are shown. The dashed curve is the PWIA calculation of Selleri[9], while the solid lines are smooth curves drawn through the values calculated by Bertini[8].

Fig. 2 : Cross section ratios $\sigma(\pi^- C^{12})/\sigma(\pi^+ C^{12})$ as a function of pion energy for the reactions $C^{12}(\pi^-,\pi^- n)C^{11}$ and $C^{12}(\pi^+,\pi^+ n+\pi^o p)C^{11}$. The experimental points are from our data and those of Chivers et al[6]. The solid lines are smooth curves drawn through the ratios deduced from the calculated points of Bertini[8] for $\sigma(\pi^- C^{12})$ and $\sigma(\pi^+ C^{12})$. The dashed line is a smooth curve drawn through the ratios deduced from the pion-proton cross sections.

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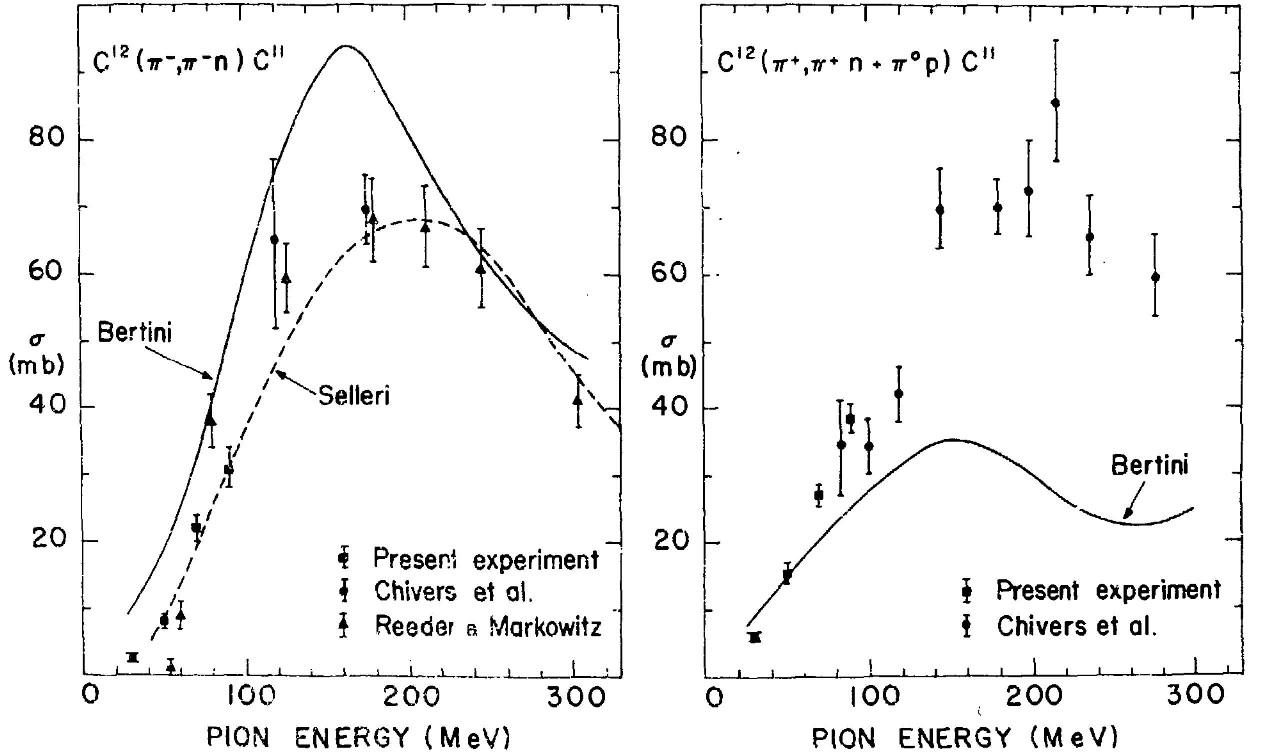
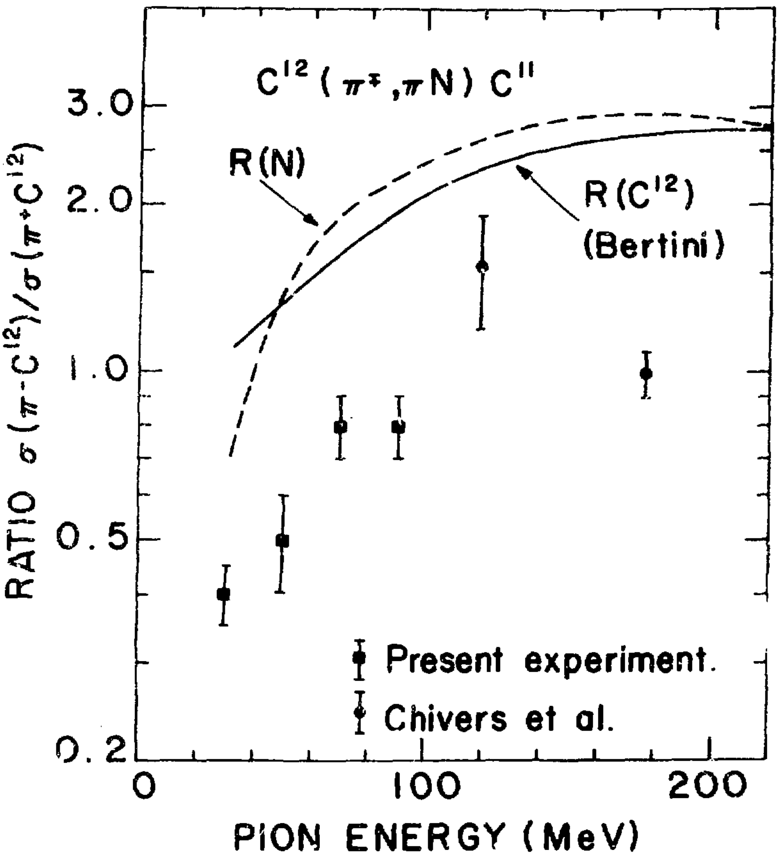


C^{12}(π^-,π^-n) C^{11}
80
60
40
20
σ
(mb)
Bertini
Selleri
Present experiment
Chivers et al.
Reeder & Markowitz
0
100
200
300
PION ENERGY (MeV)
C^{12}(π^+,π^+ n + π^0p) C^{11}
Bertini
Present experiment
Chivers et al.

Fig. 1



$C^{12}(\pi^{\mp},\pi N)C^{11}$
R(N)
$R(C^{12})$
(Bertini)
Present experiment.
Chivers et al.
RATIO $\sigma(\pi^- C^{12})/\sigma(\pi^+ C^{12})$
PION ENERGY (MeV)
3.0
2.0
1.0
0.5
0.2
0
100
200