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PION SINGLE CHARGE EXCHANGE (π^+,π^0) ON ^{13}C AND ^{11}B FROM 30 TO 90 MeV

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Abstract

The cross sections for the reactions $^{13}C(\pi^+,\pi^0)^{13}N$ and $^{11}B(\pi^+,\pi^0)^{11}C$ were measured over the energy range of 30 to 90 MeV by an activation method. The data for ^{13}C correspond solely to the excitation of the ground state analog. The excitation curve for ^{13}C is flat, contrary to available theoretical predictions for analog state transitions.

The description of pion single charge exchange reactions in nuclei is currently not well understood. Plane wave impulse calculations[1-3] for (π^+,π^0) analog state transitions have been performed for light nuclei, and give an excitation curve with a maximum near the energy of the (3,3) resonance. Distorted wave calculations have also been carried out for these transitions, employing the Kisslinger non-local optical potential[4-6] and the Distorted Wave Impulse Approximation (DWIA)[7]. The results predict a minimum in the excitation function, in the region of the (3,3) resonance. The calculations may be very sensitive to the inclusion of spin-flip terms and properly antisymmetrized wave functions[8].

Single charge exchange measurements (π^-,π^0) on several nuclei, to the sum of all final states, are available at 70 MeV[9]. Few pion single charge exchange reactions to single states have been performed to date. Among other pion reactions in light nuclei, Chivers et al.[10] investigated the reactions $^{13}C(\pi^+,\pi^0)^{13}N$ and $^{10}B(\pi^+,\pi^0)^{10}C$ at 180 MeV and the reaction $^{11}B(\pi^+,\pi^0)^{11}C$ in the energy range of 80 to 280 MeV. The measurements were done by observing the β^+-activity of the residual nucleus. This method yields the total cross section for transitions to all the bound states of the final nucleus. For ^{13}C one measures the transition to the isobaric analog state ; for ^{11}B the transitions to the analog state plus 9 bound states, and for ^{10}B the transitions to two bound states, neither of which is an analog state. The excitation curve for ^{11}B has a maximum in the (3,3) resonance region. Besides the measurement of $^{13}C(\pi^+,\pi^0)^{13}N$ at 180 MeV, the only other observed (π^+,π^0) transition to a single state, the analog state, is the measurement of $^{91}Zr(\pi^+,\pi^0\tilde{p})^{90}Zr$ at 30 MeV[11].

We can summarize, at this point, the two major open questions concerning the excitation curve for pion single charge exchange reactions at low energies ($E_\pi \leq 100$ MeV) as well as in the resonance region, as follows : 1) Is the excitation function different for transitions to analog states and other states, and 2) Is there a difference between light and heavy elements ? The latter question is prompted by the fact that the appearance of a minimum or a maximum in the resonance region seems to be due to absorption effects, which may take place predominantly at the surface of the nucleus. Since the relative importance of the surface is different in light and heavy nuclei, it is conceivable that the (π^+,π^0) excitation curve will be different.

We concern ourselves, in the present work, mainly with the low energy behavior of the (π^+,π^0) reaction cross section in light nuclei. We report here the results of measurements of the reactions $^{13}C(\pi^+,\pi^0)^{13}N$ and $^{11}B(\pi^+,\pi^0)^{11}C$ as a function of energy from 30 to 90 MeV. The secondary π^+ beam from the Saclay electron linear accelerator was used. Our measurements to date were limited by the maximum available pion energy at Saclay of about 100 MeV. Typical beam intensities on target were about 5×10^5 pions per second. The beam had an approximate Gaussian shape of about 2×3 cm^2 (FWHM) with an energy spread of ±10%. The pion beam also contained positrons, muons and protons. The positrons and muons are not expected to contribute much to our cross sections. The protons were stopped in aluminum absorbers. 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[(12)] values of the pion yield. Variations of beam intensity with time were monitored with a small plastic scintillator placed directly behind the target, and recorded in a multiscaler. This detector was movable and was also used to measure the beam profile for each energy.

The ^{13}C target consisted of powder, enriched to 97%, pressed and enclosed in polythene, which reduced the overall enrichment to 95%. The final form of the target was a disk, 3 cm in diameter, and 0.82 gr/cm^2 in thickness. The ^{11}B targets consisted of natural boron powder with thicknesses ranging from 0.1 to 2.0 gr/cm^2.

For the ^{13}C measurement we observed the 10.0 min β^+ activity of ^{13}N and the 20.4 min activity of ^{11}C. In this way, the following reactions were observed :

A ...... $^{13}C(\pi^+,\pi^o)^{13}N$

B ...... $\begin{cases} ^{13}C(\pi^+,pn)^{11}C \\ ^{12}C(\pi^+,\pi^+n + \pi^op)^{11}C \end{cases}$ (5% contamination in ^{13}C target)

All other reactions leading to the same final nuclei are expected to be negligibly small. Bombardments were carried out for a period of one to two half lives of the activity to be measured. The annihilation γ rays from the β^+ decay were measured in coincidence by two NaI (Tl) detectors in a shielded area. The decay curves were recorded in a multiscaler for about 4 half lives. Each decay curve was analyzed by a least-square-fit program. The efficiency of the coincidence system was measured with a standard ^{22}Na source. A correction of about 10% was made for the γ absorption in the target.

The decay curves for the ^{13}C target are dominated by the 20.4 min. activity of reactions (B). As the pion energy increases it becomes progressively more difficult to see the 10.0 min. activity of reaction (A). In our analysis, we always assumed a 20.4 min. activity to be present and searched for an additional activity. The half life of this second activity was always found to lie between 7 and 13 min. The counting rates at the end of the bombardments were obtained by fixing the half lives of the two activities at 10.0 min. and 20.4 min. For every energy, we took between two to four separate measurements and averaged the results appropriately. A typical decomposition is shown in Fig. 1. For the ^{11}B target, we observed only the 20.4 min. activity of ^{11}C. The results for ^{13}C and ^{11}B together with the results of some calculations are given in Figs. 2 and 3 respectively. The errors shown include only statistical and fitting errors. We estimate the error in the overall normalization, due to uncertainties in the pion beam intensity, to be 25%. This does not affect the shape of the excitation curve. The cross sections are shown at the average pion energy inside the target.

The significant feature of the present results is that the excitation curve for ^{13}C is relatively flat between 30 and 90 MeV. This energy behavior is in disagreement with the existing non-local optical model and DWIA[7] calculations [4-6] (see Fig. 2).

Our results for ^{11}B show that the excitation curve between 50 and 90 MeV is flat, while the cross section is lower at 30MeV. Our ^{11}B results are in agreement with the existing data[10] in the overlapping energy range of

70 to 100 MeV. We note that the cross section for ^{11}B (analog transition + 9 other transitions) at low energies is appreciably larger than for ^{13}C, (analog transition only). This suggests that the non-analog state transitions in the $^{11}B(\pi^+,\pi^o)^{11}C$ reaction are important.

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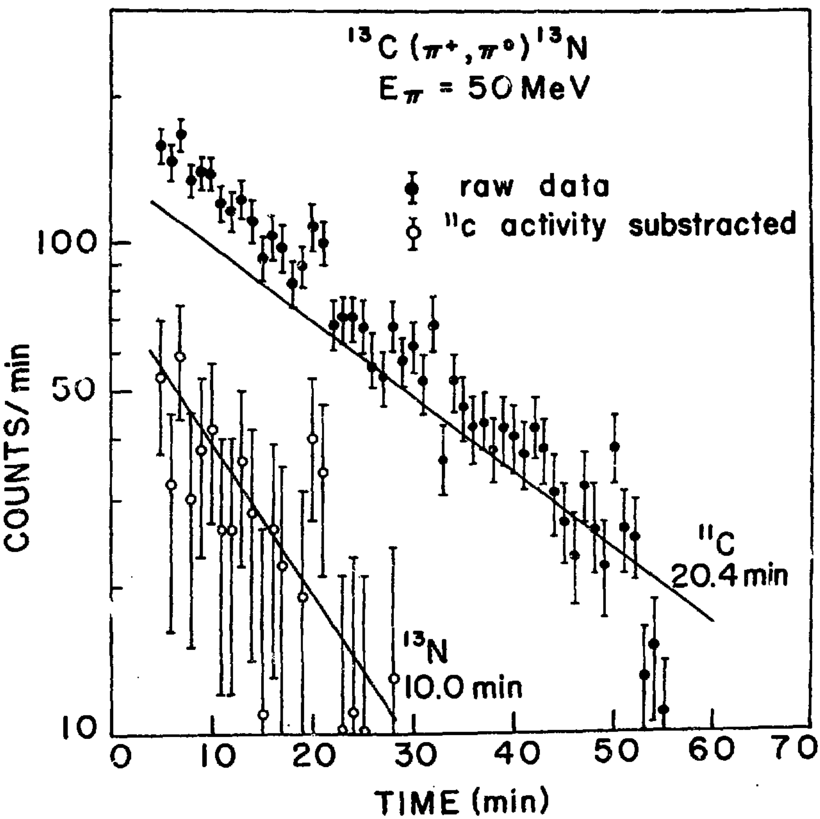
Figure Captions

Fig. 1 : Decay curve of β^+ activity from $^{13}C + \pi^+$ at 50 MeV showing decomposition into ^{11}C and ^{13}N activities. Room background of about 6 counts per minute was subtracted.

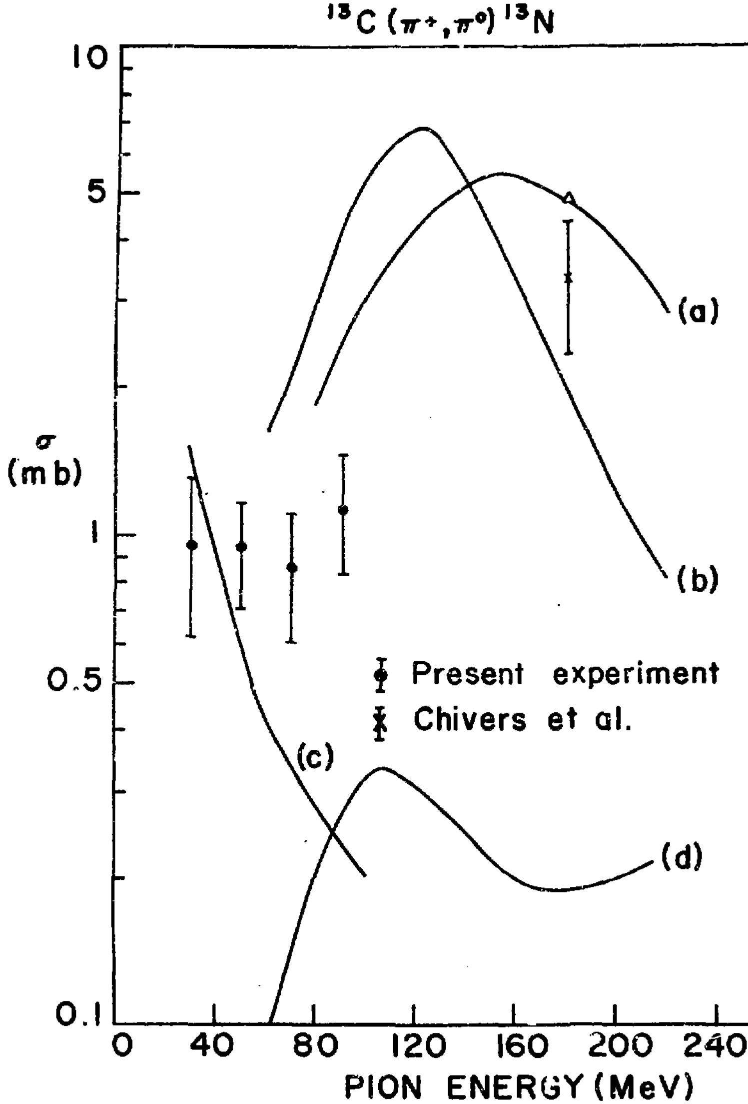
Fig. 2 : Excitation function for the $^{13}C(\pi^+,\pi^0)^{13}N$ reaction obtained from this experiment and from Ref.(10). Curve (a) is a calculation by Sakamoto(1), curve (b) is a calculation by Bakke and Reitan(2), curve (c) is our interpolation of the results of Koren(4) for ^{7}Li and ^{27}Al, curve (d) is a calculation by Wilkin(7), and the Δ is a calculation by Karapetyan and Korenman(3).

Fig. 3 : Excitation function for the $^{11}B(\pi^+,\pi^0)^{11}C$ reaction obtained from this experiment and from Ref.(10). The Δ is the result of a calculation by Karapetyan and Korenman(3).



$^{13}C(\pi^+,\pi^0)^{13}N$
E_π = 50 MeV
raw data
^{11}c activity substracted
^{11}C
20.4 min
^{13}N
10.0 min
COUNTS/min
TIME (min)
100
50
10
0
10
20
30
40
50
60
70

Fig. 1



$^{13}C(\pi^+,\pi^0)^{13}N$
10
5
1
0.5
0.1
σ (mb)
0
40
80
120
160
200
240
PION ENERGY (MeV)
(a)
(b)
(c)
(d)
Present experiment
Chivers et al.

Fig. 2

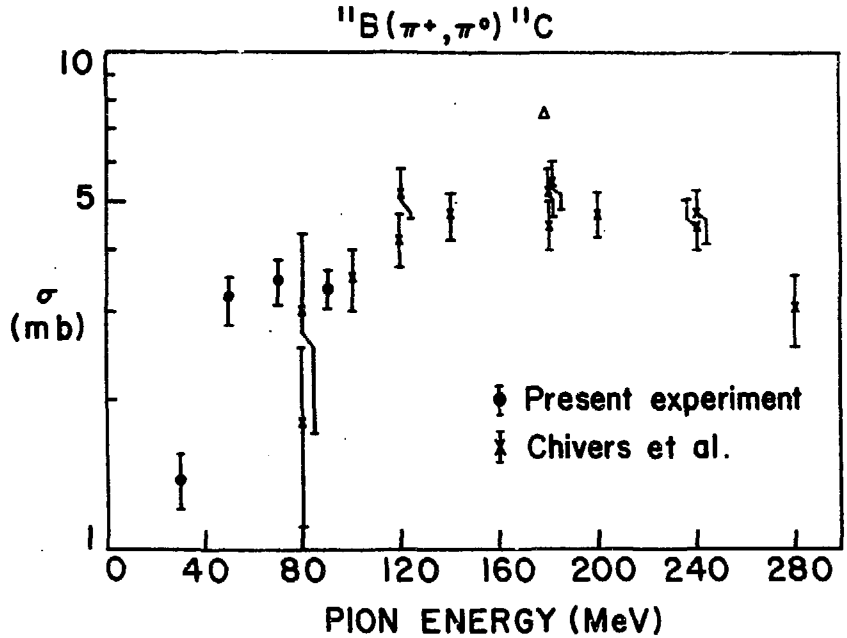

$^{11}B(\pi^+,\pi^0)^{11}C$
10
5
1
σ
(mb)
0
40
80
120
160
200
240
280
PION ENERGY (MeV)
Present experiment
Chivers et al.

Fig. 3