POSITIVE PION PRODUCTION FROM THE BOMBARDMENT OF ^{11}B, ^{12}C AND ^{40}Ca BY 146-159 MeV POLARIZED PROTONS

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As part of the continuing program to study the A(p,π^+){A+1} reaction near threshold, polarization asymmetries of this reaction for transitions to several discrete final states in ^{11}B, ^{13}C and ^{41}Ca have been measured. One of the motivations for and an advantage of studying the reaction near threshold is that the outgoing pions should be dominated by s and p waves. This assumption is important because it limits the number of experimental points needed to determine the angular distribution of the analyzing power to 3 or 4 angles, when the corresponding differential cross is well established.

The asymmmetries for the ^{10}B($\vec{p}$,π^+)^{11}B, ^{12}C($\vec{p}$,π^+)^{13}C, and ^{40}Ca($\vec{p}$,π^+)^{41}Ca reactions were measured at polarized proton bombarding energies of 154, 159 and 146 MeV, respectively. The outgoing pions, which ranged in energy from 5-12 MeV in the center-of-mass, were detected with the D$\bar{D}$ pion spectrometer.[1] The ^{10}B and ^{40}Ca targets were chosen to complement a set of angular measurements[2] for transitions to the ^{11}B and ^{41}Ca ground states. The ^{12}C target was chosen because of the different structures of the ^{13}C ground state (1/2$^-$) and 3.09 MeV state (1/2$^+$), and because

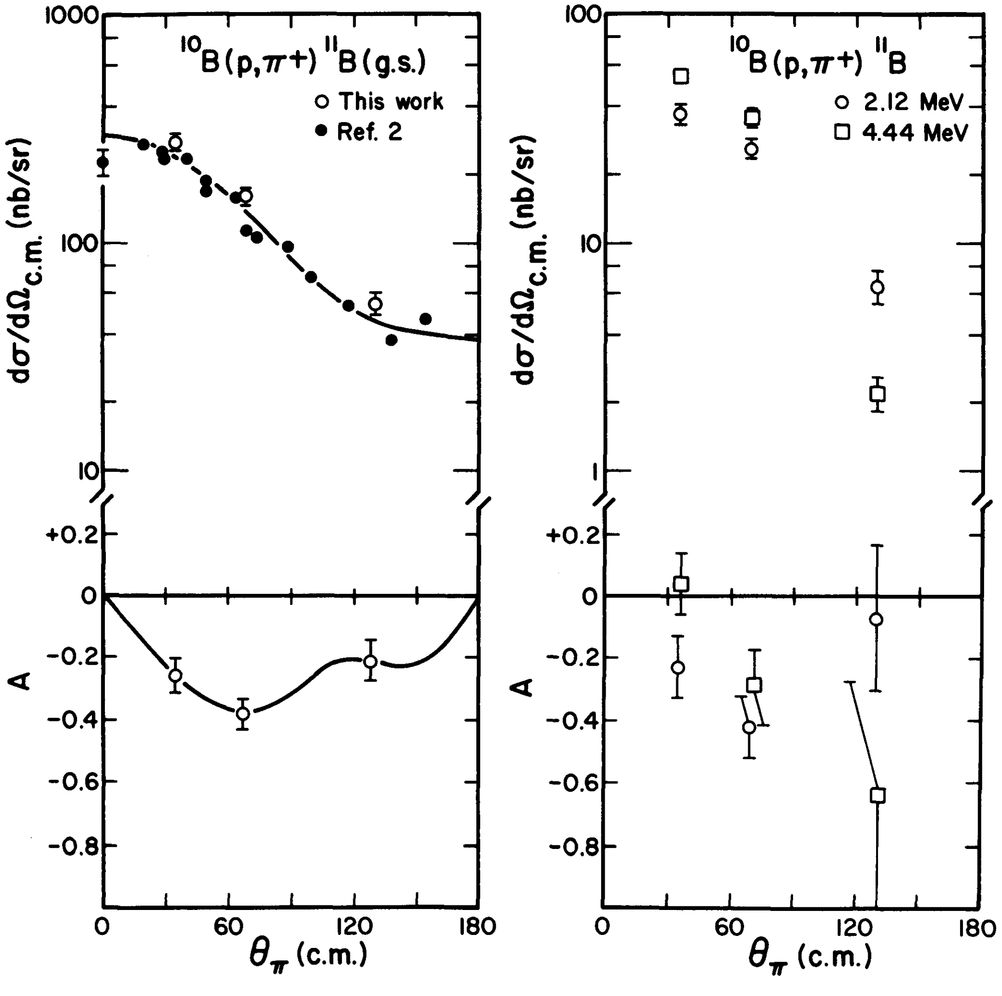

Figure 1. Results of the ^{10}B($\vec{p}$,π^+)^{11}B asymmetry measurements. The curves in this figure and the succeeding figures are polynomial fits which are discussed in the text.

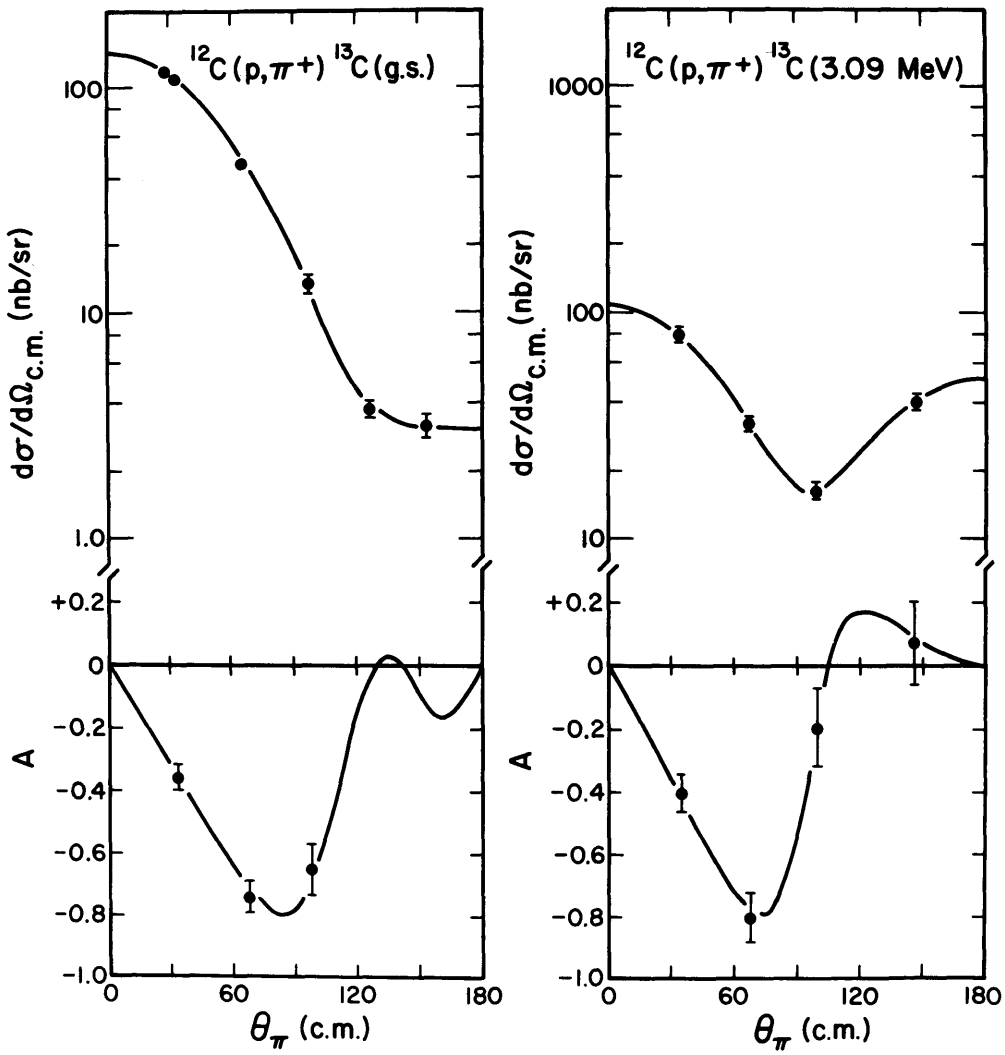

Figure 2. Results of the $^{12}C(\vec{p},\pi^+)^{13}C$ *asymmetry measurements.*

the J=1/2 spins of these states allow a complete reaction analysis to be made using a method described by Pollock, et al.[3] Furthermore, the asymmetry measurements of the $^{12}C(p,\pi^+)^{13}C$ reaction at 200 MeV[4] allow an interesting comparison to be made of the analyzing powers at two different energies.

The results of the present measurements are shown in Fig. 1-3, where the differential cross sections as well as the asymmetries have been plotted as a function of the c.m. angle θ. Figure 1 contains the results for the ^{11}B ground state and the 2.12 and 4.44 MeV excited states. The ^{11}B ground state involves primarily the $1p_{3/2}$ neutron orbital, while the excited states have more complex configurations. Figure 2 shows the results for the ^{13}C ground and 3.09 MeV states, both of which are good single particle states involving the $1p_{1/2}$ and $2s_{1/2}$ orbitals, respectively. Information was also obtained for the 3.68-3.85 MeV doublet in ^{13}C. This doublet was not resolved in the present experiment; the asymmetries of the doublet were observed to be negative, but not as large as those for the lower lying states. Figure 3 contains the results for the transition to ^{41}Ca ground state, which is a good single particle state involving the $1f_{7/2}$ orbital.

Several features can be seen in the present results: 1) the observed asymmmetries are generally negative; 2) the large negative asymmetries observed

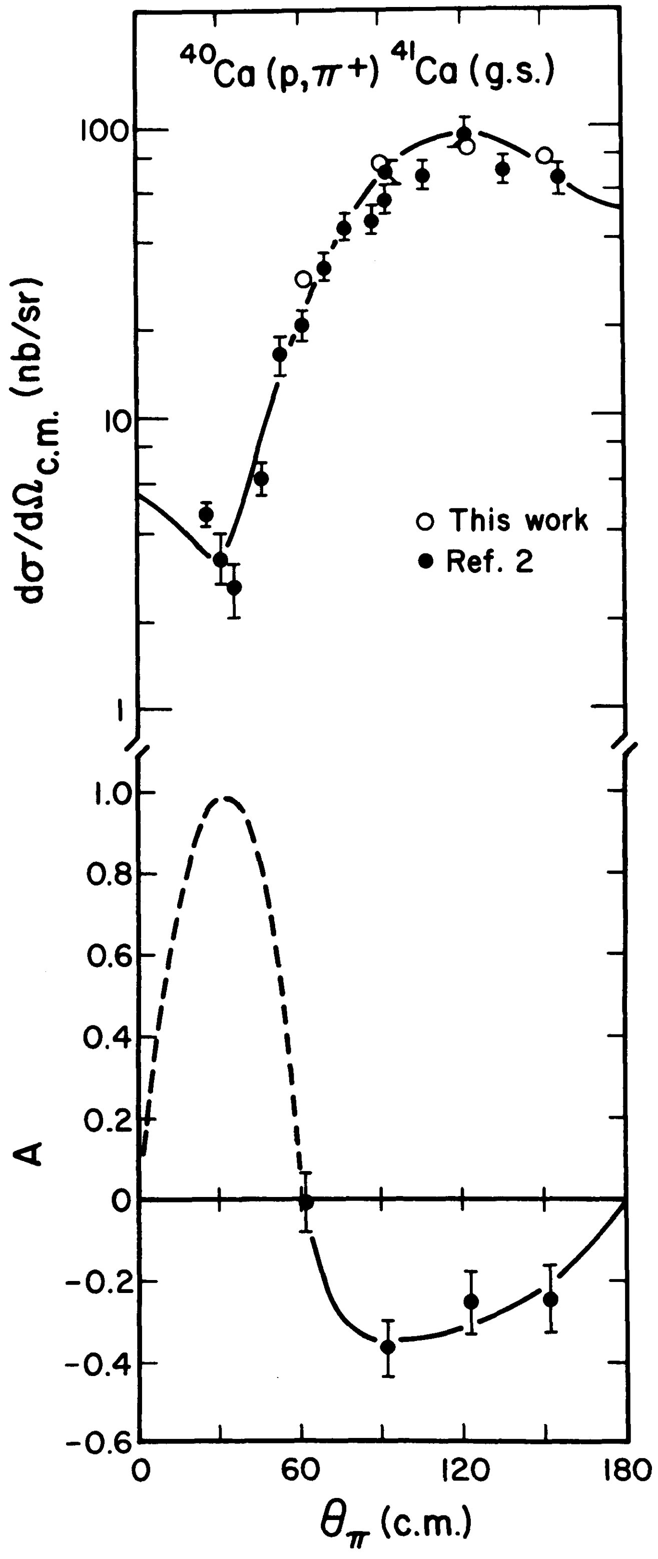

Figure 3. Results of the $^{40}Ca(\vec{p},\pi^+)^{41}Ca$ asymmetry measurements.

by Auld, et al.[4] for the $^{12}C(\vec{p},\pi^+)^{13}C$ reaction at 200 MeV are also seen to persist at 159 MeV, indicating that the asymmetries are not sensitive to the pion energies near threshold ($T_\pi^{c.m.} \leq 40$ MeV); and 3) the asymmetries exhibit some state dependence.

The curves drawn through the differential cross section data points in Figs. 1-3 are polynomial fits to order $\cos^3\theta$. With these fits, curves for the angular distribution of the analyzying power $A(\theta)$ were determined by fitting $(d\sigma/d\Omega)A(\theta)/\sin\theta$ to order $\cos^2\theta$. These polynomial fits will be a valid description if s and p wave outgoing pions dominate with the d wave included only through its interference with the s and p waves. The validity of this approximation has been tested[3] on a number of light nuclei in this pion energy region. The angular distribution for the analyzing power of the ^{41}Ca ground state is not well defined at forward angles and is denoted by a dotted line.

Recently there have been two different theoretical attempts to explain the observed $(\vec{p},\pi^+)$ asymmetries. Tsangarides[5] has calculated polarization asymmetries within the framework of the stripping model including the effects of both proton and pion distortions. While the sign of the analyzing power is given correctly for the $^{10}B(p,\pi^+)^{11}B$(g.s.) and $^{12}C(p,\pi^+)^{13}C$(g.s.) reactions, the calculations are extremely sensitive to the form of the pion production operator {(static (λ=0) or Galilean invariant (λ=1)} and to both proton and pion distortions. For the $^{40}Ca(p,\pi^+)^{41}Ca$(g.s.) reaction, λ=1 gives a reasonably good fit to the differential cross section data but the wrong sign for the analyzing power, whereas λ=0 gives the correct sign for the analyzing power but fails to reproduce its angular variation and the differential cross section data.

Gibbs[6] has taken a different approach. He assumes that the pion originates in the nucleus and is knocked-out by the incoming proton. Preliminary calculations give negative asymmetries which are not inconsistent with the experimental results.

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5) M.C. Tsangarides, thesis, Indiana University, 1979, IUCF Internal Report #79-4.

6) W. Gibbs, Invited Paper, LAMPF Workshop on Nuclear Structure with Intermediate Energy Probes, Los Alamos, 1980 (unpublished).

HIGH RESOLUTION STUDIES OF THE (p,π^+) REACTION ON 1p SHELL NUCLEI AT Ep=200 MeV

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It was shown by Dahlgren et al.[1] in one of the early Uppsala papers on nuclear pion production near threshold that the $^{12}C(p,\pi^+)^{13}C$ reaction produces final states of complicated structure just as strongly as states that can be reached by the direct transfer of a neutron. This is illustrated by the upper spectrum shown in Fig. 1, which was taken recently at IUCF with an overall energy resolution of 170 keV. The fact that the $1p_{1/2}$, $2s_{1/2}$ and $1d_{5/2}$ single-particle states at 0.0, 3.09 and 3.85 MeV, respectively, and the two particle-one hole states at 3.68, 6.86 and 9.50 MeV are populated about equally provided early evidence in support of a two-nucleon[2] or multistep[3] reaction mechanism.

Recent high resoultion studies of the (p,π^+) reaction on other targets in the p-shell indicate that strong production of core-excited states may be the exception rather than the rule. Figure 2 (top) shows a $^{10}B(p,\pi^+)^{11}B$ spectrum taken at IUCF with an overall energy resolution of 210 keV. The five low-lying states of odd-parity in ^{11}B are believed to arise mainly from configurations comprised of $p_{3/2}$ and $p_{1/2}$ nucleons and are well described by the shell model based on the intermediate coupling scheme.[4] The states at 0.00($3/2^-$) and 4.44($5/2^-$) MeV which are strongly excited in the (p,π^+) reaction also are populated strongly in the (d,p) reaction and have the largest single-particle spectroscopic factors. The 2.14($1/2^-$) state, which is forbidden by

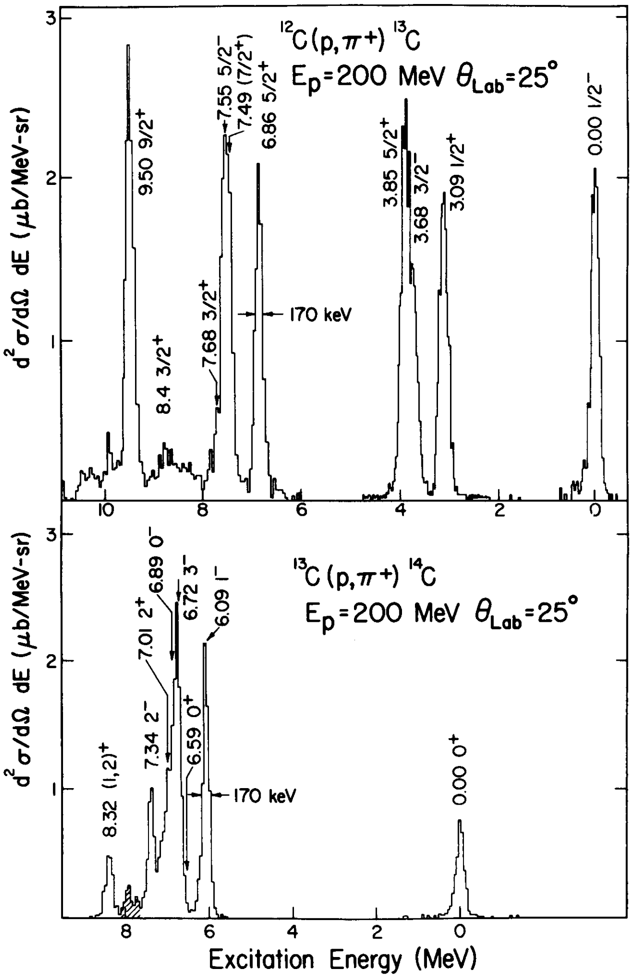

Figure 1. Pion energy spectra from the reactions $^{12}C(p,\pi^+)^{13}C$ and $^{13}C(p,\pi^+)^{14}C$ at T_p=200 MeV and θ_π(lab) = 25°.