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Brief Reports

Brief Reports are short papers which report on completed research or are addenda to papers previously published in the **Physical Review**. *A Brief Report may be no longer than 3½ printed pages and must be accompanied by an abstract.*

$^{3}\mathrm{He}(\vec{\mathrm{p}},\pi^{+})^{4}\mathrm{He}$ reaction near threshold

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Angular distributions of the differential cross section and analyzing power for the reaction $^{3}\mathrm{He}(\mathrm{p},\pi^{+})^{4}\mathrm{He}$ have been measured at $T_{\mathrm{p}}=178$ and 198 MeV. The analyzing powers, which have not been measured previously in the near threshold region, are similar to those of the elementary $\mathrm{pp}\rightarrow\pi^{+}\mathrm{d}$ reaction at low energies reflecting the dominance of the two-nucleon reaction mechanism.

The aim of current microscopic models of nuclear pion production is to relate the production process in complex nuclei to the elementary $NN\rightarrow NN\pi$ reaction.[1] Clearly, a necessary step in such an approach is to understand pion production in very light nuclear systems. Differential cross section and analyzing power data for the $\mathrm{pd}\rightarrow\pi^{+}\mathrm{t}$ reaction exist over a wide energy range.[2] Studies of pion production on the helium isotopes are less common, particularly in the near threshold region. The $^{3}\mathrm{He}(\mathrm{p},\pi^{+})^{4}\mathrm{He}$ reaction has been studied previously at a number of energies,[3] but there has been only one previous measurement[4] of the analyzing power, which was made at $T_{\mathrm{p}}=800$ MeV—far above the production threshold. Since spin dependent observables provide stringent tests of theoretical models, it is important to know the analyzing power at other energies. We report here on the first measurements of the analyzing power of the $^{3}\mathrm{He}(\vec{\mathrm{p}},\pi^{+})^{4}\mathrm{He}$ reaction in the near threshold region.

The present measurements were performed at the Indiana University Cyclotron Facility (IUCF) using polarized proton beams with energies of 178 and 198 MeV, corresponding to pion center-of-mass energies of 11 and 25 MeV, respectively.

The pions were detected in a quadrupole-dipole-dipole-multipole (QDDM) magnetic spectrometer.[5] The detector array included a position sensitive wire chamber followed by three scintillators. For particle identification, two time-of-flight measurements were made; one between the first and second scintillators and the other between the first scintillator and the cyclotron radio frequency signal. An event was defined by a fast coincidence between the anode of the wire chamber and two or three scintillators, depending on the pion energy.

The geometry of the high-pressure room-temperature gas target cell is shown in Fig. 1. The collimator sleeve held a 0.0025 cm thick Havar pion exit window close to the center of the target cell to reduce multiple scattering of the pions in the target gas, and also to prevent incident protons from scattering directly from the cell windows into the spectrometer. The 0.02 cm thick Havar beam entrance and exit windows were designed so that the cell could be used over the full angular range of the spectrometer (25–155°). The gas cell was positioned on a remote controlled turntable, so that it could be rotated with the spectrometer. The collimator alignment was carefully checked with a laser beam and also by proton elastic scattering. The entrance slits of the QDDM spectrometer together with the front collimator inside the sleeve defined the effective solid angle of the spectrometer. The effective target thickness was calculated from the collimator geometry.[6] The target gas pressure was monitored during the experiments to an accuracy better than 1%, and the temperature to better than 1° C. No macroscopic heating of the target gas due to the beam was observed. Assuming negligible localized heating, the target gas density was known to better than 1.5%. As an overall check on the effective target thickness and detector efficiency, the angular distribution of the proton-^{4}He elastic cross section was measured at $T_{\mathrm{p}}=198$ MeV. The results were in good agreement with those of Moss *et al.*[7]

The total error in the absolute cross sections due to systematic errors, including those resulting from pion decay in flight and misidentification of muons as pions, was estimated to be ±5%. Most of the systematic errors cancel out for

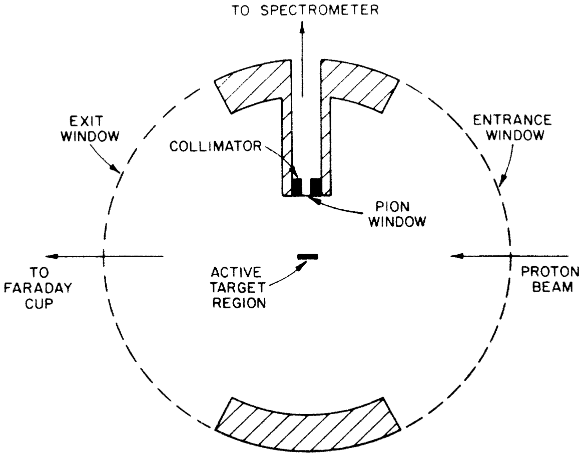

FIG. 1. Schematic diagram (top view) of the ^{3}He gas target cell.

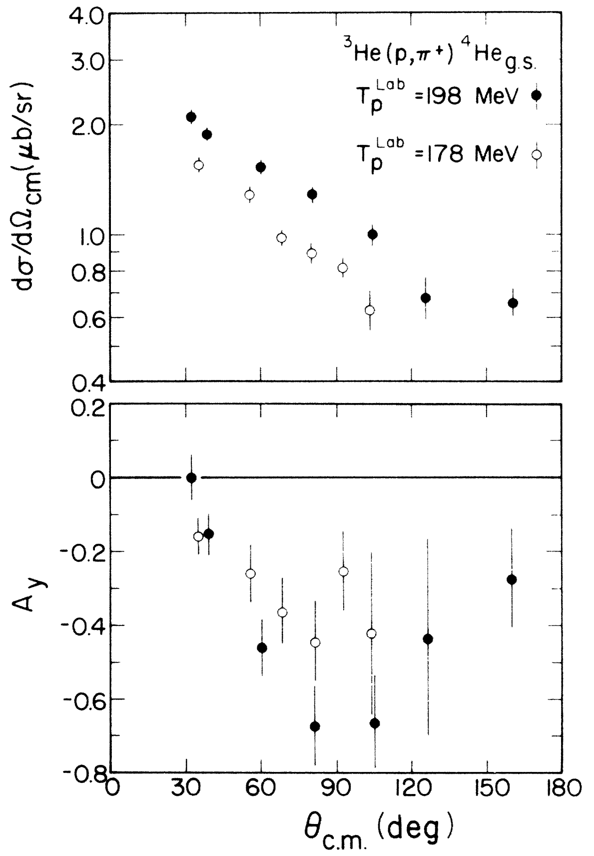

FIG. 2. Differential cross sections and analyzing powers for the reaction ^{3}He($\vec{p}$,π^+)^{4}He$_{g.s.}$ at $T_p=178$ MeV (open circles) and 198 MeV (solid circles), plotted as a function of the center-of-mass pion angle.

the analyzing power measurements. More details on the experimental setup and procedures are given in Ref. 8.

Angular distributions of the differential cross sections and analyzing powers measured at $T_p=178$ and 198 MeV are plotted in Fig. 2 and listed in Table I. The error bars for the differential cross sections represent only statistical errors; those for the analyzing powers include both statistical errors and the uncertainty in the beam polarization. The cross sections are in good agreement with those of Willis *et al.*,[3] but, assuming charge symmetry and detailed balance, are in apparent disagreement with those of Källne *et al.*[9] for the ^{4}He(π^-,n)^{3}H reaction. There have been no previous measurements of the analyzing power of the ^{3}He(p,π^+)^{4}He reaction in the near threshold region.

It has been known for some time that the analyzing powers of $A(\vec{p},\pi^+)A+1$ reactions in the near threshold region are, with few exceptions,[10] remarkably insensitive to nuclear structure effects and strikingly similar to those of the elementary $\vec{p}p\rightarrow\pi^+d$ reaction.[11] This is usually interpreted as evidence for the dominance of a two-nucleon production mechanism in nuclei. The ^{3}He($\vec{p}$,π^+)^{4}He analyzing powers reported here follow this trend, suggesting that they result primarily from the elementary two-nucleon process itself and that initial and final state interactions involving the other nucleons produce relatively small effects.

TABLE I. Differential cross sections and analyzing powers for the reaction ^{3}He(p,π^+)^{4}He$_{g.s.}$.

T_p[a] (MeV)	θ cm (deg)	$d\sigma/d\Omega(\theta)$ (μb/sr)	$A_y(\theta)$
178.2	35.5	1.55 ±0.06	−0.16 ±0.06
	56.1	1.28 ±0.07	−0.26 ±0.08
	69.1	0.99 ±0.06	−0.36 ±0.09
	81.6	0.90 ±0.06	−0.44 ±0.11
	93.4	0.82 ±0.06	−0.25 ±0.11
	104.4	0.63 ±0.08	−0.42 ±0.22
198.4	32.9	2.10 ±0.09	0.0 ±0.06
	39.3	1.87 ±0.07	−0.15 ±0.06
	60.5	1.52 ±0.07	−0.46 ±0.08
	81.6	1.29 ±0.08	−0.68 ±0.11
	105.4	1.00 ±0.07	−0.67 ±0.13
	126.7	0.68 ±0.11	−0.44 ±0.27
	160.8	0.66 ±0.06	−0.27 ±0.14

[a] Average proton laboratory energy at the center of the gas target.

The analyzing powers of the pp→π^+d, pd→π^+t, and $A(p,\pi^+)A+1$ reactions have quite different energy dependences. For pp→π^+d, A_y changes sign from negative to positive values slowly as the bombarding energy increases from 350 to 500 MeV.[12] The reversal in sign of A_y is more sudden for the pd→π^+t reaction,[2] and occurs with striking suddenness (between 200 and 225 Mev bombarding energy) for the ^{12}C(p,π^+)^{13}C$_{g.s.}$ reaction.[13] For the ^{3}He(p,π^+)^{4}He reaction, A_y is mostly negative at $T_p=178$ and 198 MeV (see Fig. 2), while at 800 MeV[4] it is negative for $\theta_\pi<40°$ and positive for $40°<\theta_\pi<90°$, reaching a value of $+0.9$ at $\theta_\pi=60°$. In the absence of a reliable theoretical treatment, it is not obvious what kinematic transformation to apply when comparing p+ nucleus pion production with the elementary pp→π^+d process,[11] or even what the appropriate kinematic variables are.[14] Höistad has pointed out[4] that the 198 and 800 MeV ^{3}He(p,π^+)^{4}He analyzing power data coincide approximately in shape when A_y is plotted versus the transverse momentum transfer rather than angle or total momentum transfer, but the significance of this observation is not clear. More data on the analyzing power of the ^{3}He(p,π^+)^{4}He reaction at several energies between 200 and 800 MeV are needed.

Although the pp→π^+d reaction is reasonably well understood,[15] there have been few quantitatively successful calculations of the (p,π^+) reaction on complex nuclei, and most attempts to fit simultaneously both differential cross section and analyzing power data have failed. Since any realistic microscopic model of nuclear pion production must be able to explain the production process in light nuclear systems, the present results should provide useful constraints on theory in the near threshold region. The data presented here will provide an early test of a two-nucleon model code currently under development.[16]

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