PHYSICAL REVIEW C VOLUME 51, NUMBER 3 MARCH 1995

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 four printed pages and must be accompanied by an abstract.*

Measurement of the ^{3}H(π^+,^{3}He)π^0 differential cross section at T_π=142 MeV

M. L. Dowell,* W. Fong,† J. L. Matthews, H. Park, M. Wang, and M. E. Yuly‡
Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Masschusetts 02139

E. R. Kinney
Department of Physics, University of Colorado, Boulder, Colorado 80309

P. A. M. Gram
Los Alamos National Laboratory, Los Alamos, New Mexico 87545

D. A. Roberts
Department of Physics, University of Michigan, Ann Arbor, Michigan 48109

G. A. Rebka, Jr.
Department of Physics and Astronomy, University of Wyoming, Laramie, Wyoming 82071
(Received 22 November 1994)

Measurements of the differential cross section for the pion-induced isobaric analog transition in the A=3 system are presented. This measurement, in which low energy recoiling nuclei were detected, is the first at forward pion angles and incident energies where the spin flip ($\Delta S = 1$) contribution to the differential cross section is predicted to have its strongest influence. Although the data are not sufficiently accurate to support a definitive conclusion, they agree best with a calculation that includes this contribution.

PACS number(s): 25.80.Dj, 25.80.Gn, 27.10.+h

The excitation of an isobaric analog state through pion charge exchange is an important reaction channel in pion-nucleus interactions. This reaction is often referred to as elastic charge exchange since the initial and final nuclear states are identical except for the third component of isospin. The three-nucleon system is the simplest system in which an isobaric analog transition may be observed, i.e., ^{3}H(π^+,π^0)^{3}He or ^{3}He(π^-,π^0)^{3}H.

In 1975, Sparrow [1] predicted that the spin-flip ($\Delta S =$ 1) contribution to the elastic charge exchange reaction should be quite large in the three-nucleon system at incident pion energies between 100 and 200 MeV, viz., a factor of up to 5 enhancement in the differential cross section in the region of the non-spin-flip ($\Delta S = 0$) minimum. Subsequently, several authors [2–11] have calculated cross sections for elastic scattering and single charge exchange. The important features of these charge exchange calculations are a strongly forward-peaked angular dependence and a nearly flat energy dependence for the total cross section in the Δ-resonance region. This energy dependence is perhaps surprising when compared to the strongly peaked energy dependence for charge exchange on a free nucleon and for pion elastic scattering on $A = 3$ nuclei.

The pion-induced isobaric analog transition between ^{3}He and ^{3}H may be observed in four different ways. Either the ^{3}He(π^-,π^0)^{3}H or ^{3}H(π^+,π^0)^{3}He reaction may be observed by detecting either a neutral pion or a recoil nucleus. As the differential cross section decreases by roughly two orders of magnitude from forward to backward π^0 angles, the peak in the π^0 spectrum associated with this transition becomes quite small compared with the yield from quasifree charge exchange. In the only previous measurement at forward angles, in which the π^0 was detected, the isobaric analog peak became indistin-

*Present address: Joint Institute for Laboratory Astrophysics, Boulder, CO 80309-0440.
†Present address: Johns Hopkins Oncology Center, Baltimore, MD 21287.
‡Present address: Department of Physics, Northwest Nazarene College, Nampa, ID 83686.

guishable from the quasifree yield at pion center-of-mass angles greater than 90° [12]. These data also appear to disagree by a factor of about 3 with recoil measurements at large π^0 angles [4–7,12]. Detection of a recoil nucleus is a definitive indication that the isobaric analog transition has taken place, since the ground states of ^{3}H and ^{3}He are the only bound states of these nuclei. However, previous experimental studies that employed this technique have been limited to large π^0 center-of-mass angles by their inability to detect very low energy recoil nuclei.

In the present experiment ^{3}He nuclei produced by the $^3\mathrm{H}(\pi^+,^3\mathrm{He})\pi^0$ reaction in a 2 mg/cm^2 tritiated titanium foil were detected by a double-focusing 180° vertical bend spectrometer. This spectrometer was equipped with an array of nineteen 400 μm silicon surface barrier detectors at the focal plane. A thin plastic scintillator located downstream from the solid state detectors is the final element in the particle detection and identification system. The flight path from the target to the detectors is in vacuum to minimize energy loss and multiple scattering. The momentum acceptance of the spectrometer is approximately 8.5%; its solid angle is approximately 15 msr. The combination of magnetic analysis and observed energy deposit in one or more detectors provided the capability to detect and identify ^{3}He nuclei in the energy range from 1.4 to 80 MeV, corresponding to a range in center-of-mass pion angle of $45° < \theta_{\mathrm{c.m.}} < 130°$ at an incident energy of 142 MeV. The small angle limit is set by the lowest detectable energy and the large angle limit by the smallest angle 25°, to which the spectrometer may be rotated. Although this spectrometer and its instrumentation have successfully detected charged pions in a number of experiments [13,14], the present work represents the first time that it has been used to detect heavier charged particles.

The focus and steering of the incident pion beam were monitored continuously throughout the experiment using a small high-rate multiwire proportional chamber [15]. The beam flux was measured with an ionization chamber which was calibrated by comparisons of the proton yield from π^+p elastic scattering measurements, using CH_2 and matching graphite targets, with known values [16] as determined from phase shift calculations at the same incident beam energy. The beam flux was typically 10^8 π/s. The uncertainty in the measurement of the pion flux was less than 5%. Observation of π^+p elastic scattering also served to establish the momentum acceptance of the spectrometer. The tritium content of the tritiated foils was determined by comparing measured ^{3}H yields from $\pi^+\,^3$H elastic scattering with known values [17]. The uncertainty in the tritium content of the targets was less than 8%. The yield was estimated with the help of a Monte Carlo simulation [18] that included the magnetic transport properties of the spectrometer, the momentum spread of the incident beam, energy loss in the targets, and the response of its focal plane detectors to predict the shape of the momentum spectrum for a given reaction.

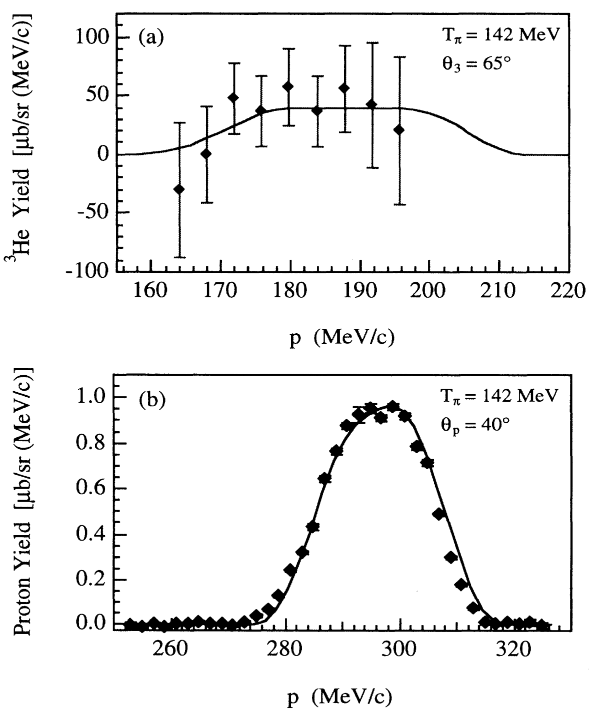

FIG. 1. Momentum spectra of (a) ^{3}He particles from $^3\mathrm{H}(\pi^+,^3\mathrm{He})\pi^0$ at T_π=142 MeV and θ_3=65° and (b) protons from $^1\mathrm{H}(\pi^+,\mathrm{p})\pi^+$ at T_π=142 MeV and θ_p=40°. The solid line corresponds to the Monte Carlo prediction for the elastic peak shapes. In this example roughly 80% of the ^{3}He elastic peak was measured.

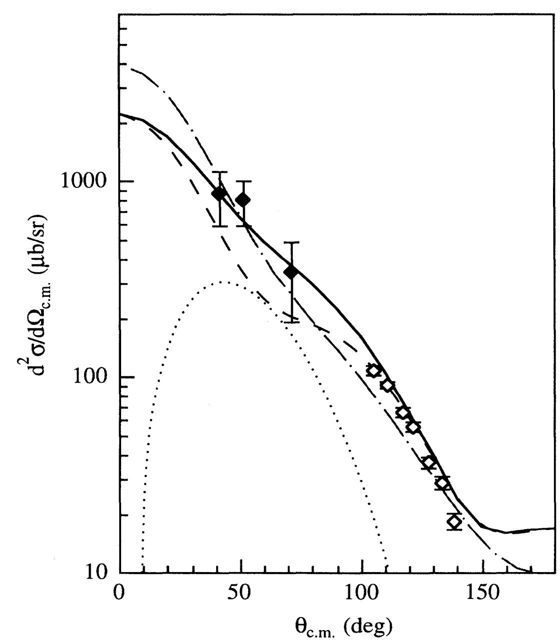

FIG. 2. Center-of-mass differential cross sections for the $^3\mathrm{H}(\pi^+,^3\mathrm{He})\pi^0$ reaction at 142 MeV. The solid points are from this work; the open points are from measurements by Glodis *et al.* [20] at 148 MeV. The solid curve represents a πN T-matrix calculation by Gibbs [8]; the dashed and dotted curves are the non-spin-flip and spin-flip contributions, respectively. The dot-dashed curve is the result of a coupled channel calculation by Tiator [10].

Comparisons of the Monte Carlo results for proton and ^{3}He momentum spectra from π^+p elastic scattering and elastic single charge exchange, respectively, are shown in Fig. 1. Momentum spectra obtained from the tritiated foil and from a matched pure Ti foil were integrated using the predicted shape and subtracted to determine the net ^{3}He yield from elastic charge exchange at a given angle of observation. The relatively large background from titanium is chiefly responsible for the large statistical uncertainty seen in these data; the yield of ^{3}He nuclei from pion bombardment of Ti is about 1/8 that of elastic charge exchange at the most forward angle, becoming about 1/3 at 70°. These yields from Ti compare well with the measurements of Kaufman *et al.* [19] on Ag at a nearby energy when scaled by $A^{2/3}$. We note that when planning the experiment it had been expected that the tritium content of the target would be 3 times greater than was obtained.

Differential cross sections were measured at an incident pion energy of 142 MeV and π^0 center-of-mass angles of 42.0°, 51.5°, and 71.0°. The results are shown in Fig. 2, together with earlier measurements [20] at larger angles. Although the data exhibit large statistical uncertainties and have a limited angular range, comparison with recent theoretical calculations [8,9] suggests that inclusion of the spin-flip contribution to the differential cross section is necessary for these calculations to reproduce the measured angular distribution at this energy. The curves shown in Fig. 2 represent two calculations of elastic single charge exchange in the three-nucleon system. The cross section predicted by Gibbs [8] is derived from a separable πN T-matrix calculation using multiple scattering theory [9]. This model includes assumptions about the off-shell behavior of the πN scattering amplitudes and the nuclear binding energy. That predicted by Kamalov, Tiator, and Bennhold [10,11] is derived from a coupled channels calculation. The present data are consistent with the smooth angular dependence of both calculations.

We would like to thank the LAMPF staff for their support in mounting and running the experiment. We also thank W. R. Gibbs and L. Tiator for several helpful discussions. This work was supported in part by the U.S. Department of Energy.

[1] D. A. Sparrow, Phys. Lett. **58B**, 309 (1975).
[2] M. Wakamatsu, Nucl. Phys. **A340**, 289 (1980).
[3] W. J. Gerace *et al.*, Phys. Rev. C **22**, 1197 (1980).
[4] A. T. Hess and B. F. Gibson, Phys. Rev. C **13**, 749 (1976).
[5] J. M. Eisenberg and V. B. Mandelzweig, Phys. Lett. **53B**, 405 (1975).
[6] K. P. Lohs and V. B. Mandelzweig, Z. Phys. A **283**, 51 (1977).
[7] R. H. Landau, Phys. Rev. C **15**, 2127 (1977).
[8] W. R. Gibbs (private communication).
[9] W. R. Gibbs and B. F. Gibson, Phys. Rev. C **43**, 1012 (1991).
[10] L. Tiator (private communication).
[11] S. S. Kamalov, L. Tiator, and C. Bennhold, Universität Mainz Technical Report No. MKPH-T-92-13, 1992; Phys. Rev. C **47**, 941 (1993).
[12] M. D. Cooper *et al.*, Phys. Rev. C **25**, 438 (1982).
[13] D. M. Manley, Los Alamos Technical Report No. LA-9101-T, 1981.
[14] A. T. Oyer, Los Alamos Technical Report No. LA-6599-T, 1976.
[15] G. J. Krausse and P. A. M. Gram, Nucl. Instrum. Methods **156**, 365 (1978).
[16] J. B. Walters and G. A. Rebka, Jr., Los Alamos Technical Report No. LA-7731-MS, 1979.
[17] C. Pillai *et al.*, Phys. Rev. C **43**, 1838 (1991).
[18] M. L. Dowell, Los Alamos Technical Report LA-12691-T, 1994.
[19] S. B. Kaufman *et al.*, Phys. Rev. C **32**, 1977 (1985).
[20] P. Glodis *et al.*, Phys. Rev. Lett. **44**, 234 (1980).