

CHARGE EXCHANGE

THE ${}^4\text{He}(\vec{p},n){}^4\text{Li}$ REACTION AT 100, 147, AND 200 MeV

C. M. Edwards, M. A. Palarczyk, D. Dehnhard, and J. L. Langenbrunner
University of Minnesota, Minneapolis, Minnesota 55455

B. Brinkmüller
*Universität Karlsruhe, 7500 Karlsruhe 1, Federal Republic of Germany, and
Paul Scherrer Institut, 5232 Villigen, Switzerland*

L. C. Bland and D. Carman
Indiana University Cyclotron Facility, Bloomington, Indiana 47408

Introduction

During April of 1991 at the IUCF Neutron-Time-Of-Flight (NTOF) Facility we performed the first (p,n) experiment ever done on ${}^4\text{He}$. The primary goal of the experiment was the investigation of the ${}^4\text{He}(\vec{p},n){}^4\text{Li}$ reaction over a range of incident proton energies where the relative strengths of the spin-dependent and spin-independent parts of the nucleon-nucleus force change significantly. This strong energy dependence should aid in determining the contributions from resonant excitations (of different multipolarities) to the continuum spectra of ${}^4\text{Li}$.

The ${}^4\text{He}(\vec{p},n){}^4\text{Li}$ reaction will provide new information on the isovector excitations of mass-4 nuclei, and about the level parameters of states in ${}^4\text{Li}$ which have been quite controversial recently. Previous work on mass-4 nuclei^{1,2,3} have reported widths of the ground and first excited states between 1 and 5 MeV and excitation energies which differ by more than 1 MeV. The small widths were inferred from three-body decay spectra; the large widths were extracted from a phase shift analysis of proton scattering from ${}^3\text{He}$. Our experiment should allow a direct determination of the level energies and widths of states in ${}^4\text{Li}$, and, therefore, should resolve the controversy.

The Experiment

A high-pressure, low-temperature, gas target was developed for this experiment. The gas cell was a welded stainless steel box with 25 μm thick Havar entrance and exit windows separated by 5 cm. The target was mounted on a vacuum feedthrough pushrod, which enabled the placement of the cell immediately downstream from the pivot point of the "beam swinger" at the NTOF Facility; the (retractable) solid target ladder was located at the pivot point. This arrangement allowed measurements with either solid targets (required for beam setup and calibrations) or gaseous targets.

Because the cell was positioned about 6 cm downstream from the pivot point of the swinger, changing the beam angle caused the position of the beam spot on the target to change. The Havar windows, therefore, were designed to have a rectangular shape (1.6-cm high by 4.6-cm wide) to accommodate beam angle changes of up to 24° . The windows were also designed to permit an 8-mm clearance in all directions for the beam and its halo at all angles. The bursting pressure of Havar windows of these dimensions is about 10.6×10^3 Torr at room temperature and is known to increase at lower temperatures.

In order to achieve a high ratio of scattering centers in the gas to those in the windows, the gas cell was operated near liquid nitrogen temperatures. Cooling was provided by a continuous flow of liquid nitrogen through copper tubing which was in thermal contact with copper plates attached above and below the target. When filled with helium, the cell was safely operated at a pressure of 5.5×10^3 Torr and a temperature of 103 °K. This provided a ratio of scattering centers in the gas to those in the windows of 10 to 1 for ^4He , assuring a good peak-to-background ratio. The full- and empty-target spectra are shown in Fig. 1 as a function of the missing mass (MM) (or excitation energy) assuming $^4\text{He}(p,n)$ kinematics with $\text{MM} = 0$ at the $p + ^3\text{He}$ threshold. At small scattering angles (see the top half of Fig. 1 for the $\theta_{\text{lab}} = 0^\circ$ and proton energy $T_p = 100$ MeV spectra), there are prominent peaks at negative missing masses due to the excitation of the Gamow-Teller (GT) resonance in the nuclei comprising Havar. The spectrum from the $^4\text{He}(p,n)^4\text{Li}$ reaction is seen at positive missing masses, where the spectrum from reactions on Havar is featureless. At larger angles (see, for example, the 24° spectra in the bottom half of Fig. 1), the signal-to-background ratio is even more favorable because the reactions on Havar become less important and the $^4\text{He}(p,n)$ cross section has a maximum near $\theta_{\text{lab}} = 20^\circ$ between 100 and 200 MeV. Empty target spectra were taken at all angles for background subtraction.

The neutron time-of-flight spectra were measured with two fixed neutron detector stations, one located at a distance of 76 m from the target at a nominal scattering angle of 0° , the other at a distance of 50 m, nominally at 24° . Six 10-cm by 15-cm by 100-cm NE102 plastic scintillation detectors were positioned in a vertical stack in each detector station. These detectors were oriented so that their long axes were parallel to the neutron flux, and were viewed by a pair of photomultiplier tubes placed at each end of each detector. This orientation provides superior energy resolution and detection efficiency.

By changing its magnetic field, the beam swinger changes the direction of the incident proton beam between 0° and 20° , allowing measurements at scattering angles between 0° and 20° at the 0° detector station and between 24° and 44° at the 24° detector station. Spectra were taken both with spin up and down (with respect to the reaction plane) at scattering angles between 0° and 44° in approximately 5° steps at three proton energies: 100, 147, and 200 MeV.

Preliminary Results

The analysis of the $T_p = 100$ MeV data is nearly complete. Within the statistics of these data, the background-subtracted missing mass spectra (Fig. 2) show no evidence for narrow structures in ^4Li , in contrast to the claims of previous work^{1,2} which analyzed three-body decay spectra. The spectra in Fig. 1 and 2 are not corrected for neutron detection efficiency. The detector efficiencies, needed for the extraction of the differential

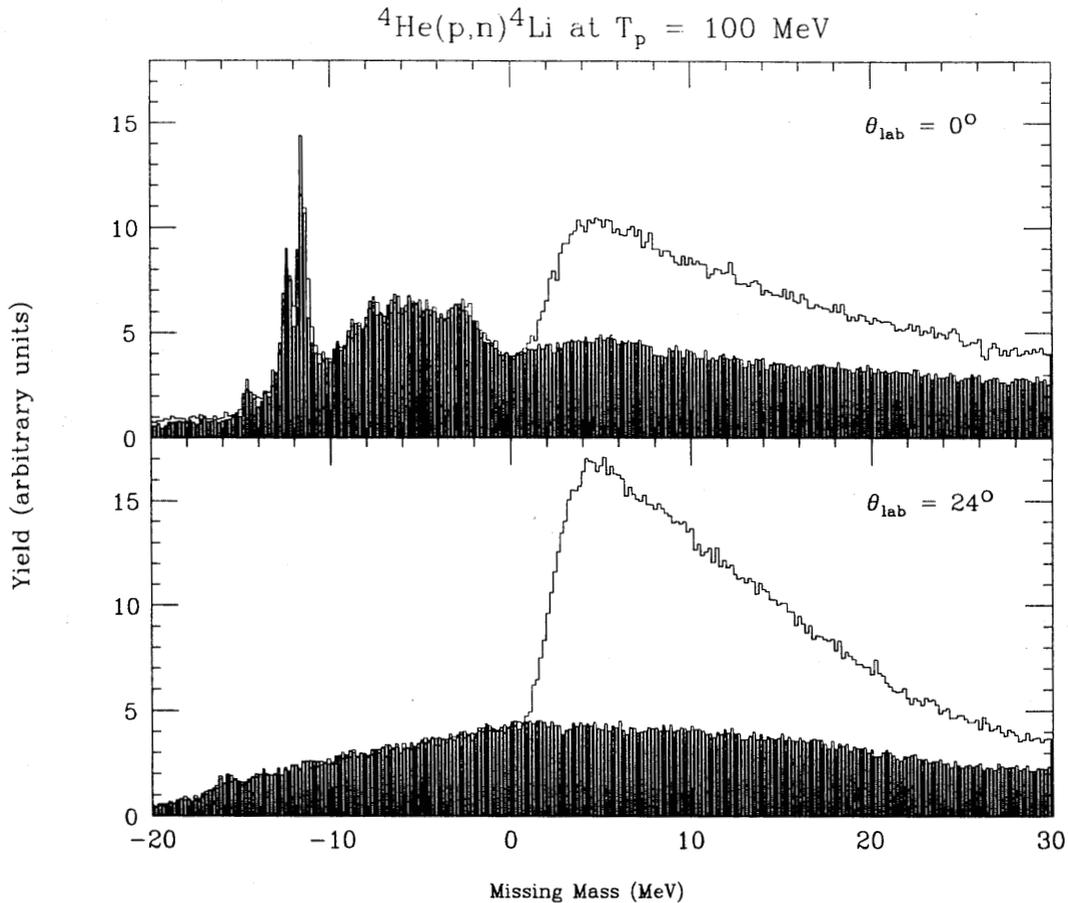


Figure 1. Missing mass spectra at $T_p = 100$ MeV for $\theta_{\text{lab}} = 0^\circ$ (top) and 24° (bottom) obtained from the gas cell filled with ${}^4\text{He}$ (unshaded histograms), and from the empty cell (shaded histograms). The GT resonances from (p,n) reactions on Havar are clearly visible at negative missing masses in the 0° spectra.

cross sections, were obtained from measurements of the yields from the (p,n) reactions on ${}^{12}\text{C}$ and ${}^{13}\text{C}$ solid targets. Some additional ${}^{13}\text{C}$ spectra were taken with a ${}^{13}\text{C}$ methane gas target.

Angular distributions of double-differential cross sections $d^2\sigma/d\Omega/dE$ and analyzing powers A_y are shown in Fig. 3 for two bites in ${}^4\text{Li}$ missing mass. We chose missing mass bites of 0 to 4 and 4 to 8 MeV because the ground state of ${}^4\text{Li}$ ($J^\pi=2^-$) is expected to dominate within the first, and the first excited state ($J^\pi=1^-$) is expected to dominate within the second of these energy bites. The angular distribution shapes of $d^2\sigma/d\Omega/dE$ and $A_y(\theta)$ differ for the two missing mass bites, and the A_y at 0° are consistent with zero, as expected, for both regions of missing mass. We are now doing DWIA calculations in order to investigate these shape differences.

${}^4\text{He}(p,n){}^4\text{Li}$ at $T_p = 100$ MeV

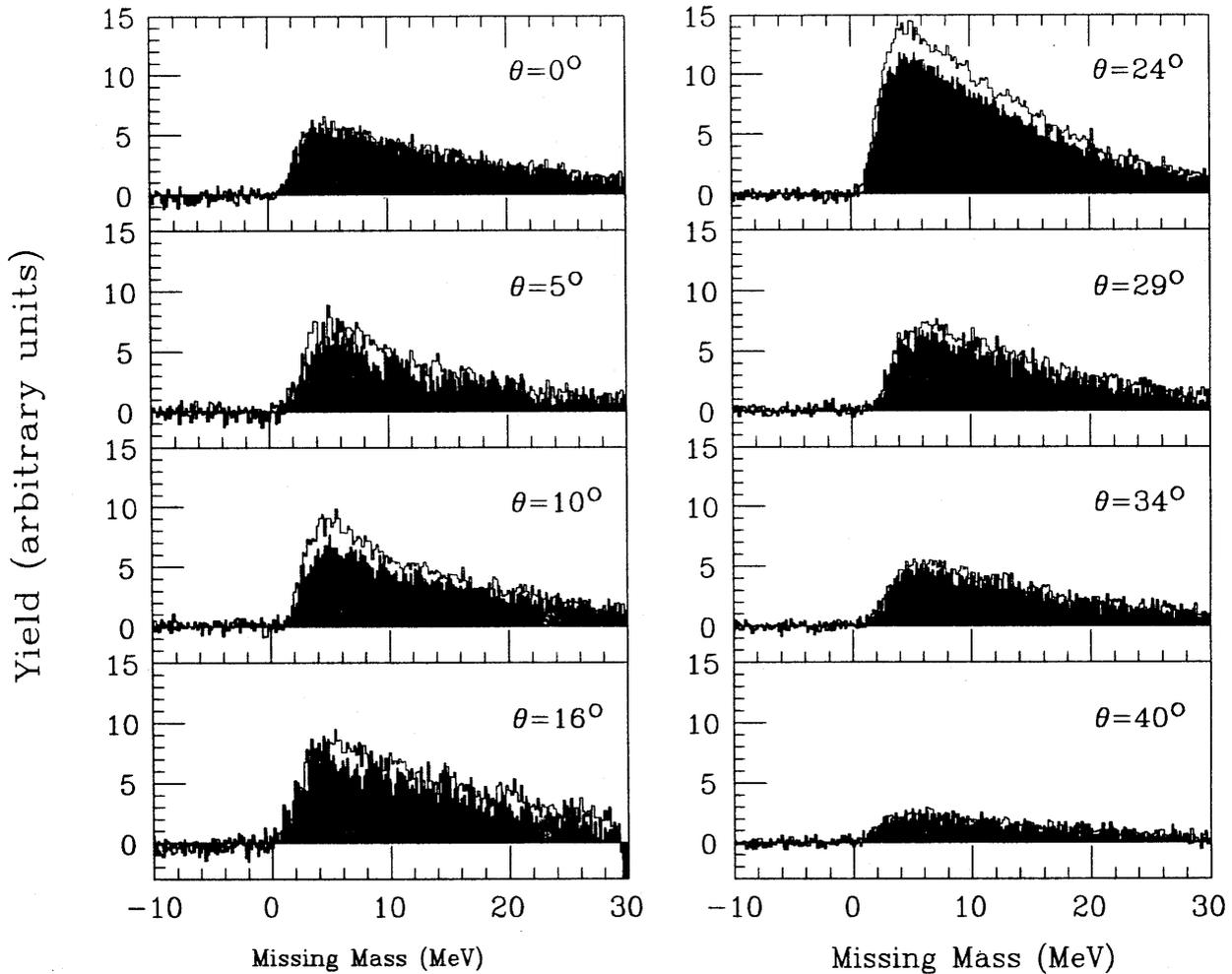


Figure 2. Missing mass spectra for ${}^4\text{He}(p,n){}^4\text{Li}$ at $T_p = 100$ MeV for spin up (shaded histograms) and spin down (unshaded histograms). There is no evidence for narrow structures in ${}^4\text{Li}$ within the statistics of these spectra. The spectra in this figure and in Fig. 1 are not corrected for the energy dependence of the neutron detection efficiency.

The neutron spectra taken at $T_p = 147$ and 200 MeV contain narrow structures in a small range of scattering angles (10° – 20°) with strong positive asymmetries. These structures appear at approximately the same missing mass with approximately the same widths as the ones extracted from the previous work on break-up reactions.^{1,2} After considerable effort in analyzing the data, however, we determined that these peaks are due to protons which elastically scattered from the target nuclei and escaped through the beam swinger's dump magnet. These protons then reached the sweep magnet (≈ 3 m downstream) at such an angle that the bending by the sweep magnet was not sufficient to prevent the protons

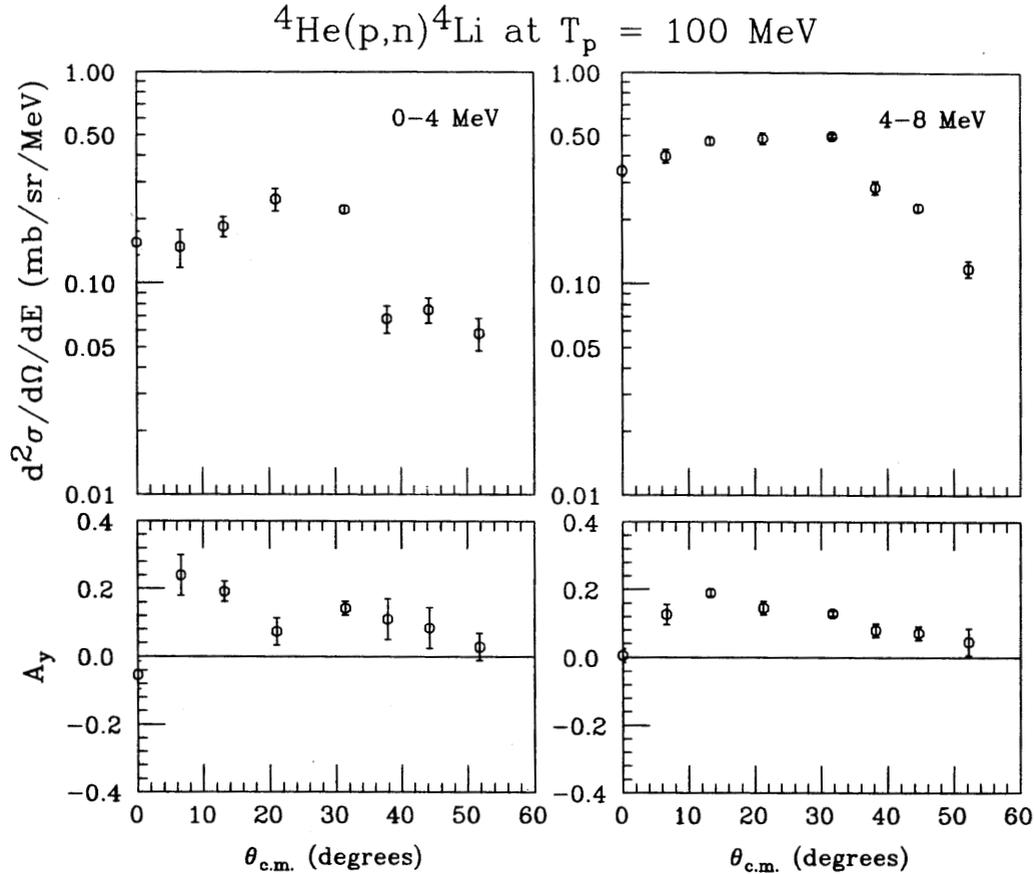


Figure 3. Angular distributions for $d^2\sigma/d\Omega/dE$ (top) and A_y (bottom) for ${}^4\text{He}(p,n){}^4\text{Li}$ at $T_p = 100$ MeV. The distributions on the left are for the 0–4 MeV energy bite in ${}^4\text{Li}$ missing mass and those on the right are for the 4–8 MeV bite. The ground state of ${}^4\text{Li}$ (2^-) is expected at about 3 MeV, and the first excited state (1^-) is expected at about 6 MeV.

from reaching the neutron detectors in the 0° detector station. After a small-angle scattering process in the air, they arrived at the neutron detectors with a time-of-flight expected of elastically scattered protons which have lost some energy in the air between the target and the neutron detectors. The peaks display the asymmetries and yields consistent with what is expected for elastic proton scattering from helium. At $T_p = 100$ MeV, the protons were stopped in the air before reaching the detectors. Thus no such structures were observed at this energy.

During the course of the experiment, we also took some ${}^3\text{He}(\vec{p},n)$ data at $T_p = 200$ MeV. The observation of peaks in the ${}^3\text{He}(\vec{p},n)3p$ spectra which were similar to the peaks in the ${}^4\text{He}(\vec{p},n){}^4\text{Li}$ spectra was a strong hint that these peaks resulted from a charged-particle contamination of the neutron spectra.

Status

A proposal update was approved by the PAC at IUCF, and 24 additional shifts of beam time have recently been scheduled to run in June of this year. This time will be used to take a set of ${}^4\text{He}(\vec{p},n){}^4\text{Li}$ spectra at both $T_p = 147$ and 200 MeV. We will also measure ${}^3\text{He}(\vec{p},n){}^3\text{p}$ spectra at both energies in order to investigate quasi-free scattering. Rather than relying on the sweep magnet to deflect charged particles away from the 0° channel, we will use a copper plate to reduce the protons' energy so that they will be stopped in the air before reaching the neutron detectors.

We expect to be able to obtain better statistics data than taken at $T_p = 100$ MeV. These data should enable us to confirm or refute the existence of narrow structures in the continuum of ${}^4\text{Li}$ states. At the higher incident energies, the spin-dependent forces become relatively more important than at 100 MeV, causing relatively larger cross sections for transitions with a spin transfer $\Delta S = 1$. Thus the transition to the 2^- ground state of ${}^4\text{Li}$, which can be reached only by $\Delta S = 1$, should become more prominent at 147 and 200 MeV. The transition to the 1^- first excited state is expected to be weaker than at 100 MeV, because it involves both $\Delta S = 1$ and $\Delta S = 0$. We hope to be able to extract the widths and centroid energies of these resonance states. We will analyze the data in the framework of the DWIA in order to extract the isovector transition strength in mass-4 nuclei and the relative contributions from the spin transfers $\Delta S = 1$ and $\Delta S = 0$.

This experiment is planned to be the Ph. D. thesis experiment of C. M. Edwards.

1. M. Bruno, F. Cannata, M. D'Agostino, and K.L. Fiandri, Phys. Rev. C **42**, 448 (1990).
2. B. Brinkmüller, H.P. Morsch, P. Decowski, M. Rogge, and P. Turek, Phys. Rev. C **42**, 550 (1990).
3. T.A. Tombrello, Phys. Rev. **138**, 40 (1965); T.A. Tombrello, Phys. Rev. **143**, 772 (1966).