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ABSTRACT

The vector analyzing powers, A_y(theta, E), of the $^{11}B(p,p)^{11}B$ and $^{11}B(p,alpha)^{8}Be$ reactions were measured as a function of angle and energy as a part of a program to study the reaction ^{11}B(p,alpha)2alpha. The experiment was performed at the Triangle Universities Nuclear Laboratory at Duke University, where the polarized proton beams between 100 nA and 600 nA with energies (E_p) of 2.65, 3.9, 4.0, 5.11, and 5.5 MeV were produced using the ABPIS source and the FN tandem. These energies were selected to be on (and off) several of the known resonances in this region. The target was composed of 35 ug/cm^2 isotopically pure (99.9% enriched) ^{11}B deposited on a 9 ug/cm^2 carbon backing. Scattered protons and emitted alpha-particles were detected by an array of six surface barrier detectors placed symmetrically to the left and right of the target. Measured asymmetries in yields from proton scattering off of the carbon backing were used to calibrate the beam polarization. The analyzing powers will be used to further our understanding of the reaction dynamics of the elastic proton channel in this energy region.

INTRODUCTION

Nuclear fission as a source of power is an issue of much debate. With the ever -growing demands for power, nuclear energy has become an indispensable source of carbon-free energy. But, with the concerns for possible radiation exposure and the chance of a repeat of Three Mile Island or, worse, Chernobyl, nuclear energy has endured much negative exposure to the public and has developed a somewhat poor reputation. Given the short history of nuclear physics as a field of study, the nuclear forces and even the structure of the nucleus itself are still not completely understood. Since so much is still unknown in the realm of nuclear physics, and most of what has become common knowledge is linked to weapons and war through the development, use, and continuing threat of the atomic bomb, the public in general has developed a sense of unease in regards to nuclear energy; in particular, unease in regards to nuclear fission as a source of energy.

Ever since the discovery of nuclear fission, scientists have searched for a means of harnessing energy from nuclear fusion. Nuclear fusion is believed to be a much safer means of producing energy than nuclear fission. Nuclear fusion also has the promise of being a much cleaner energy source than nuclear fission. While standard nuclear fusion emits immense amounts of neutron radiation, an alternate form known as aneutronic nuclear fusion has been proposed as a safer means of extracting nuclear energy. Aneutronic nuclear fusion's radiation consists of alpha-particles, which can easily be shielded against, thus greatly reducing the danger of radiation associated with nuclear fission and standard nuclear fusion. With the great potential of nuclear fusion as an energy source, many teams of scientists have formed to work together in hopes of better understanding the means by which nuclear fusion could be used.

A proposal has been made that ^{11}B could be used as an advanced fuel source in the production of energy in aneutronic nuclear fusion. The capture group at TUNL was asked to study the reaction ^{11}B(p,alpha)2alpha at specified energy ranges so that the possible energy outputs of a fusion reaction with a ^{11}B source could better be predicted. In order to better understand the ^{11}B(p,alpha)2alpha reaction, the capture group also analyzed the data from the reactions ^{11}B(p,p)^{11}B and ^{11}B(p,alpha)^{8}Be [1,2]. While these reactions have been studied many times before [3], current literature does not have information concerning the analyzing powers [4]. The measurements of ^{11}B(p,alpha)^{8}Be will be used as a first step in the analysis of ^{11}B(p,alpha)2alpha. The reaction ^{11}B(p,alpha)^{8}Be will help in finding the correction factors needed to more precisely and more accurately measure the alpha breakups inside of the reaction ^{11}B(p,alpha)2alpha.

Analyzing powers are essential in measuring the asymmetries of a reaction involving polarized reactants. By knowing the analyzing powers involved in the reaction ^{11}B(p,alpha)2alpha, a power plant implementing nuclear fusion would be able to predict the location of the particles after the reaction, and hence, would be able to more effectively collect the energy released during the reaction. Thus, by calculating the analyzing powers for several energies and angles, we would be able to design a more effective means for using ^{11}B to fuel nuclear fusion and a more effective method for gathering the energy produced during the reaction.

Analyzing powers are also essential in the analysis of a reaction. The analyzing powers are used in the calculations of both energy yields and differential cross sections. In order to fully understand the reaction ^{11}B(p,alpha)2alpha, the first step is precisely measuring the analyzing powers involved. Once the analyzing powers are known, the reaction can begin to be better understood.

PROCEDURE

Polarized proton beams between 100 nA and 600 nA with energies of 2.65, 3.9, 4.0, 5.11, and 5.5 MeV were produced using the ABPIS source and the FN tandem at TUNL and accelerated towards a target composed of 35 ug/cm^2 isotopically pure (99.9% enriched) ^{11}B deposited on a 9 ug/cm^2 carbon backing. The beams of polarized protons were collimated to 1/8" x 1/8" at the end of a snout prior to hitting the target, which was rotated at different angles throughout the experimental runs in order to measure over a wide range of angles. The elastically scattered protons and emitted alpha-particles from the collision were detected in an array of six surface barrier detectors located 15 cm from the target. The six detectors were arranged symmetrically, in two sets, with respect to the beam axis. Each set could be independently rotated. The detectors were collimated with 3/8" x 1/16" and 3/8" x 1/8" collimators located at the ends of a 2 1/8" collimator snout. The downstream beam dump was suppressed with a voltage of -300 V during the second half of the experimental run. All of the data for the 200+ runs were taken at TUNL using the TJNAF data acquisition system CODA and then analyzed at both TUNL and GCSU using the CERN C++ interpreter Root [6]. See Figure 1 for a schematic of the layout of the experiment.

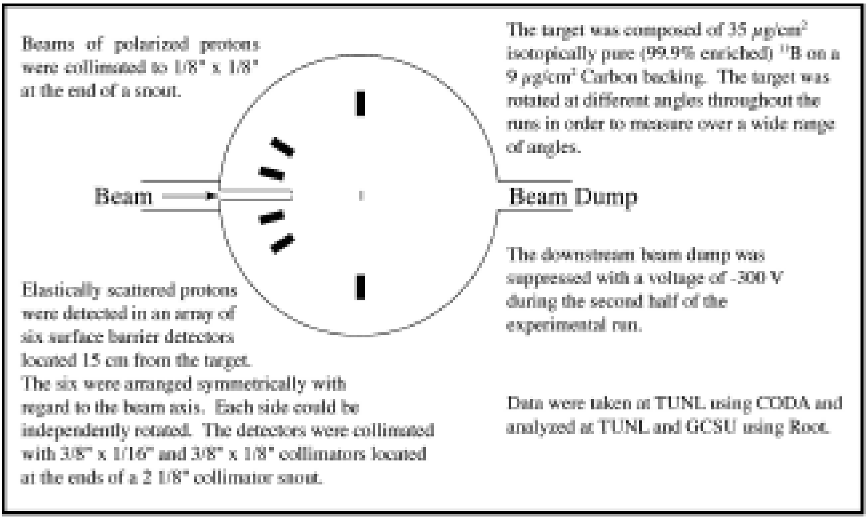

FIGURE 1. *Schematic layout for the experiment.*

ANALYSIS AND RESULTS

After acquiring the data from CODA, we were able to analyze the results of the experiment. Our first step in the analysis was to identify each peak in the spectrum for each run. See Figures 2 and 3 for typical spectra. This task was accomplished thanks to the program KinEq released by ORNL. KinEq is software used to calculate nuclear reaction kinematics. After we had identified the spectral peaks, we began our analysis of the analyzing powers for elastically scattered protons and alpha-particles from collisions of the polarized protons and the target. Since the analyzing powers are dependent upon the polarization of the protons, we first calculated the actual polarization of the beam. We had taken rough measurements of the beam polarization during the experiment. Since the vector analyzing powers for ^{12}C are well known and readily available in literature for various energies, we used data from the elastic collisions of the polarized protons and the ^{12}C backing of the target to fine tune our measurements of the beam polarization. Once we knew our beam polarization, we were able to calculate the analyzing powers for protons scattered from ^{11}B and the alpha-particles at various energies and angles.

We calculated the analyzing powers for elastically scattered protons from ^{11}B and ^{12}C and alpha-particles in the backwards angles by using the standard equation [5]:

$$A_y = ((P_1-P_2)(N_{2R}N_{1L}+N_{1R}N_{2L}) \pm \div ((P_1-P_2)^2(N_{2R}N_{1L}+N_{1R}N_{2L})^2 + 4P_1P_2(N_{2R}N_{1L}-N_{1R}N_{2L})^2) / (2P_1P_2(N_{1R}N_{2L} - N_{2R}N_{1L})),$$

where N_{1L} denotes the counts in the number one detector on the left,
N_{1R} denotes the counts in the number one detector on the right,
N_{2L} denotes the counts in the number two detector on the left,
N_{2R} denotes the counts in the number two detector on the right,
P_1 denotes the SF2 polarization, and
P_2 denotes the MF2 polarization.

We found the counts for each peak using C++ code that we ran using ROOT. ROOT contains built in functions that can be used to fit Gaussians. By fitting Gaussians to the data histograms, we were able to integrate over certain energy ranges, subtract out background noise and data from peaks other than the one we were analyzing, and acquire accurate counts for the number of backscattered polarized protons measured in each detector at various angles. Once we knew the counts in each detector for each peak at each energy, we were able to calculate our polarization from the ^{12}C peak (i.e. protons elastically scattered from the target backing), and in turn solve the above equation for the analyzing powers of protons elastically scattered from ^{11}B and alpha-particles at each energy. The results of these calculations with appropriate error bars can be seen in Figures 4-7. As expected, the analyzing powers formed a curve that approached zero as the c.m. angle went to 180 degrees.

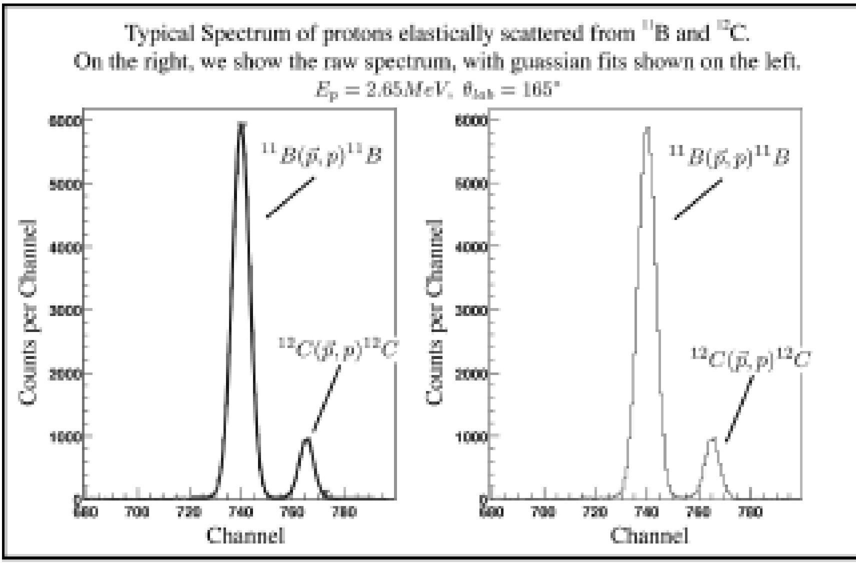

FIGURE 2. *Typical spectrum for elastic scattering from ^{11}B and ^{12}C.*

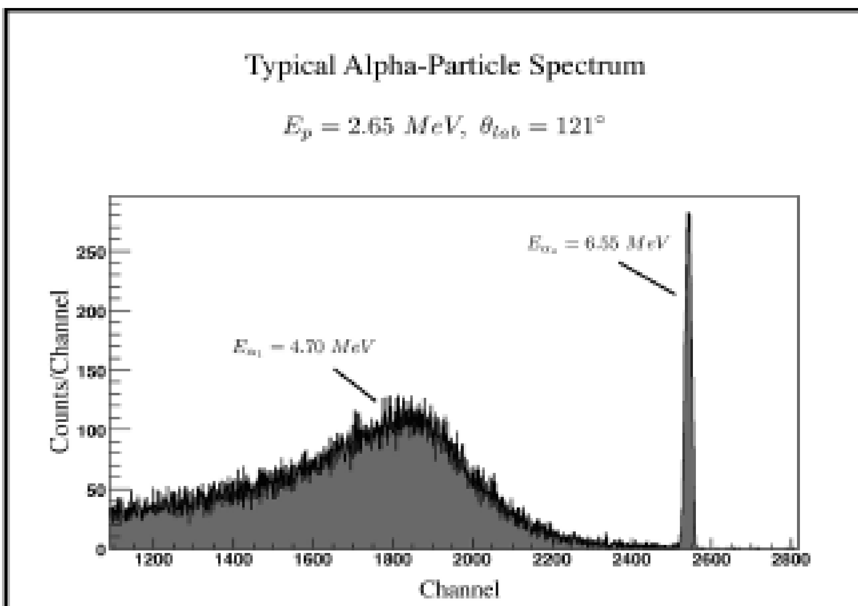

FIGURE 3. *Typical spectrum of alpha-particles. This work only contains analysis of the ground state alpha-peak.*

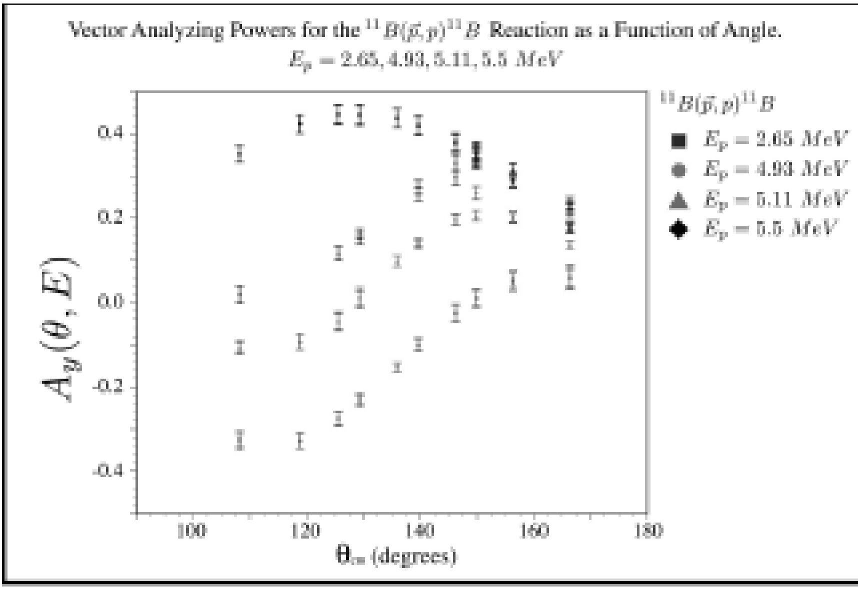

FIGURE 4. *Vector analyzing powers for $^{11}B(p,p)^{11}B$ at 2.65, 4.93, 5.11, and 5.5 MeV.*

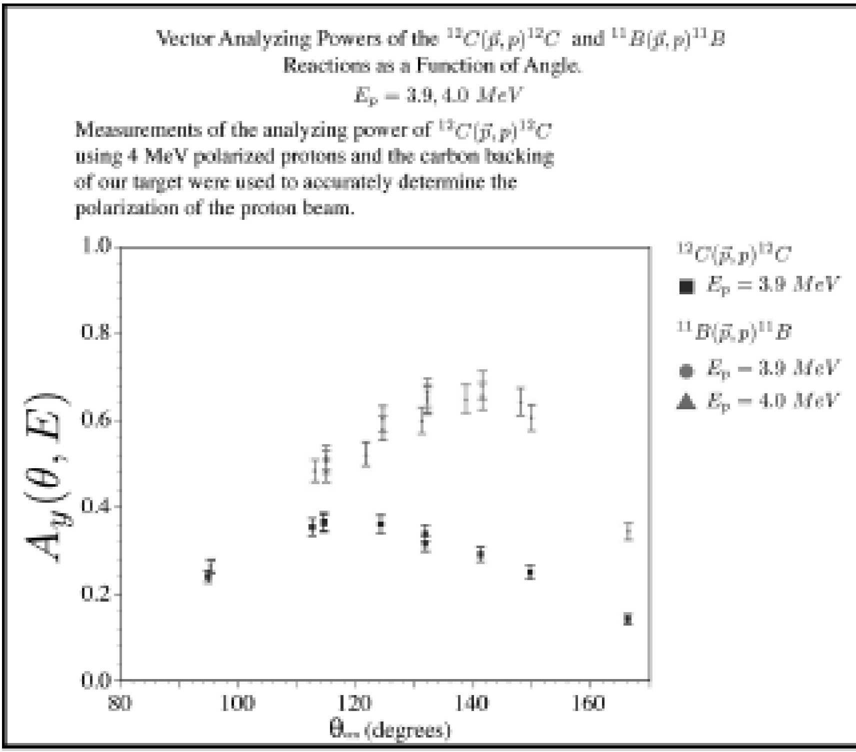

FIGURE 5. *Vector analyzing powers for $^{11}B(p,p)^{11}B$ at 3.9 and 4.0 MeV and for $^{12}C(p,p)^{12}C$ at 3.9 MeV.*

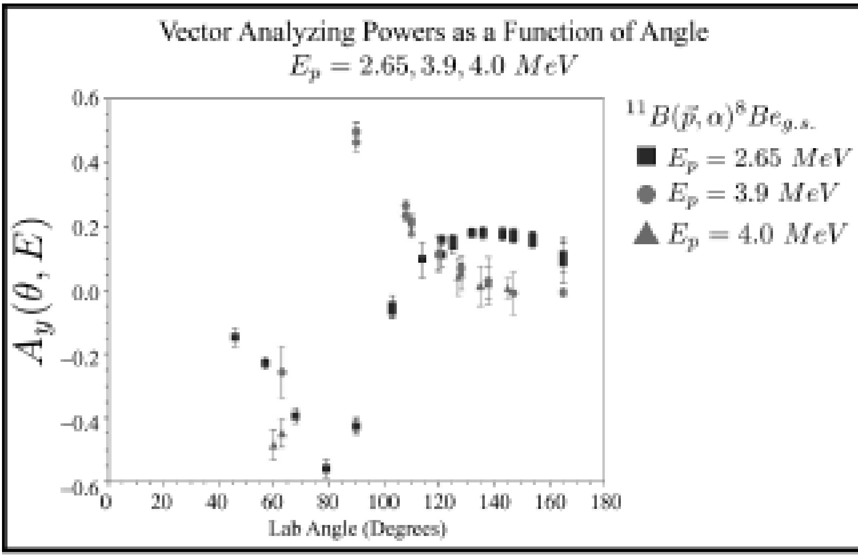

FIGURE 6. *Vector analyzing powers for* $^{11}B(p,alpha)^8Be$ *at 2.65, 3.9, and 4.0 MeV.*

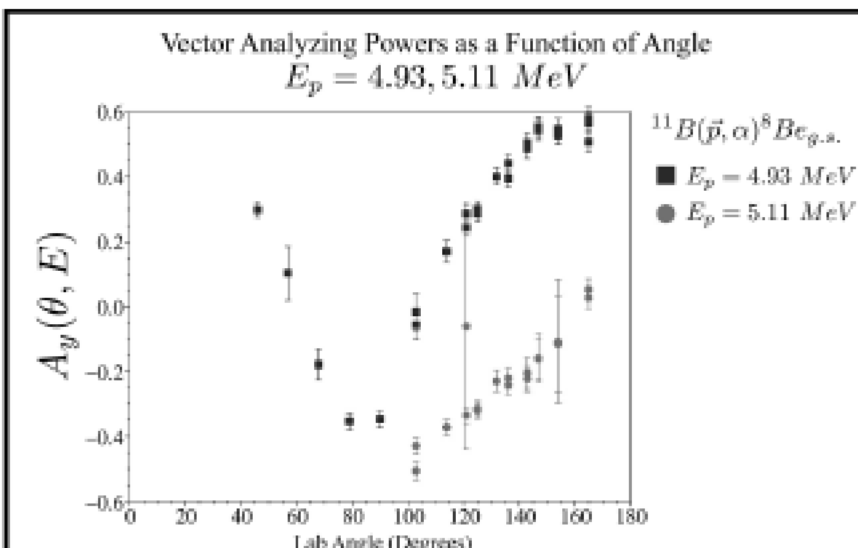

FIGURE 7. *Vector analyzing powers for* $^{11}B(p,alpha)^8Be$ *at 4.93 and 5.11 MeV.*

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