Mechanism of the $B^{10}(He^3,p)C^{12*}$ Reaction from the Proton Polarizations

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Measurements of the polarization of protons from the $B^{10}(He^3,p)C^{12*}$(4.43 MeV) reaction have been extended to the He^3 energy range from 1.75 to 2.25 MeV. The angular dependence was determined at 2.00 MeV for eight laboratory angles from 10° to 100°. In addition, measurements were made at 11 other selected angles at beam energies from 1.75 to 2.25 MeV. The results of these measurements along with previous results from measurements made at He^3 energies of 2.50 and 2.80 MeV have made it possible to study the mechanism of this reaction from the energy dependence of the proton polarizations. The smooth energy dependence observed indicates that a direct interaction mechanism is predominant for this reaction in this energy range.

I. INTRODUCTION

THE polarization of the final-state products of a nuclear reaction may be a useful means to study the mechanisms of certain types of reactions. In particular, the sensitivity of the polarization to the reaction energy may be an especially worthwhile source of information. For example, polarizations of protons obtained from elastic proton scattering show radically different results depending on whether there is a resonance corresponding to a compound nuclear state in the region of investigation.[1,2] For instance, the polarizations from p-He^4 elastic scattering are smoothly varying over a large energy range[1] since there are no corresponding compound-nucleus states in the Li^5 system. On the other hand, the protons from p-C^{12} elastic scattering exhibit a complicated behavior in the region of the compound nucleus formation of N^{13}. This complexity appears as rapid variations from positive to negative polarizations as a function of the laboratory proton energy.[2]

Measurements were made previously on the polarization of protons from the $B^{10}(He^3,p)C^{12*}$(4.43-MeV) reaction to see if they could be helpful in the analysis of the reaction mechanism.[3] The results of these measurements indicated a substantial agreement with other workers[4–6] in the interpretation of reaction mechanism. The polarization measurements as well as the angular distribution and excitation function measurements of Schiffer *et al.*[4] indicated that the reaction mechanism in the region from 2 to 5 MeV could be interpreted as dominated by two widely separated resonances. However, an interpretation of a direct interaction could not be ruled out. The possible resonances were given by Schiffer *et al.* to be at 2.0 and 3.7 MeV. The polarization measurements made at He^3 energies of 2.5 and 2.8 MeV indicated a strong similarity in the angular distributions of the polarizations at these energies and hence a weak energy dependence. It was the purpose of this investigation to extend the polarization measurements down to and below the 2.0-MeV "resonance" in order to further clarify the reaction mechanism interpretation.

II. EXPERIMENTAL PROCEDURE AND APPARATUS

A complete description of the measurement procedure and apparatus used is given in the previous paper on this work.[3] The polarizations are measured by the usual double-scattering technique in which the second scatterer (analyzer) was carbon which was contained in a plastic scintillator. Protons scattered into the CsI detectors were then defined by a coincidence between the plastic scatterer-scintillator and the detector. Two such detectors were used so that the scattering to the right and left could be measured concurrently. The polarization of the protons is then given by the asymmetry between the number of counts obtained in two side detectors divided by the polarization obtained when unpolarized protons are scattered by the analyzer. With a second scattering angle of 45°, the polarization of the analyzer was taken to be −0.50 (Basel convention).[7] Since the Q value for this reaction is 15.27 MeV, the emitted protons were sufficiently energetic, even after passing through the half-mil tantalum target backing, so as to avoid any resonances or anomalies in the compound p-C^{12} system. Thus the polarimeter was used to analyze protons in an energy region in which its analyzing power was reasonably constant. The analyzing power was checked with polarization measurements on protons from the $He^3(d,p)He^4$ reaction. These results compared quite favorably[3] with those obtained by Fann *et al.*[8]

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The scattering chamber used has a nonsymmetrical arrangement of angular ports to house the polarimeter. Such an arrangement allows measurements to be made from 0° to 135° in 5° increments, if so desired. Target alignment consisted of first centering the target in the scattering chamber and then adjusting the chamber position so that the He^3 beam hit the target on the intersection of the target with the polarimeter axis. This adjustment was accomplished by allowing the target to get hot from the incident beam so that it glowed and by visually aligning the beam, using a plastic viewer which fit in the particular polarimeter port from which the measurement was to be made. This alignment procedure insured that no detection asymmetries would be caused by beam misalignment.

The targets were prepared by evaporating enriched B^{10} (96.5% B^{10}) onto a backing of half-mil tantalum foil. Target thicknesses of approximately 300 keV were used. In order to obtain as large a counting rate as possible, the target was rotated in a plane perpendicular to the reaction plane so that higher beam currents could be used.

In addition to errors due to counting statistics, there was an increase in the polarization error of approximately 0.01. This increase was due to (1) the error in the analyzing power of the polarimeter, (2) elastic scattering effects from the ground-state proton group, (3) variations in the thickness of the second scatterer, (4) beam alignment, and (5) geometry effects due to the slope of the angular distributions. These errors are discussed more fully in the previous paper on this subject.

TABLE I. Polarization of protons from $B^{10}(He^3,p)C^{12*}$(4.43-MeV) reaction.

$E(He^3)$ (MeV)	E_{av}[a] (MeV)	θ_{lab} (deg)	$\theta_{c.m.}$ (deg)	P_1[b]	σ[c]
1.75	1.60	90	92.58	−0.11	0.10
1.80	1.65	10	10.45	+0.05	0.12
		15	15.68	−0.15	0.11
		70	72.46	+0.17	0.11
		90	92.61	−0.12	0.10
1.85	1.70	90	92.64	−0.15	0.10
1.95	1.80	90	92.71	−0.02	0.09
2.00	1.85	10	10.48	−0.22	0.10
		15	15.71	−0.12	0.07
		25	26.16	0.00	0.10
		35	36.57	−0.22	0.09
		60	62.37	−0.09	0.09
		75	77.65	−0.16	0.10
		90	92.74	−0.15	0.06
		100	102.70	+0.01	0.10
2.05	1.90	90	92.77	−0.08	0.09
2.10	1.95	90	92.80	−0.10	0.09
2.25	2.10	15	15.75	−0.23	0.08
		90	92.89	+0.17	0.10

[a] E_{av} is the average energy of the He^3 beam due to energy losses in the thick targets.
[b] P_1 is measured by double scattering from C^{12}, taking the analyzing power as −0.5, where $\mathbf{k}_{in}\times\mathbf{k}_{out}$ is positive.
[c] Accumulated error from counting statistics, analyzing power of polarimeter, inelastic scattering effects from the ground-state proton group, variations in the thickness of the second scatterer, and geometry effects due to slope in angular distribution.

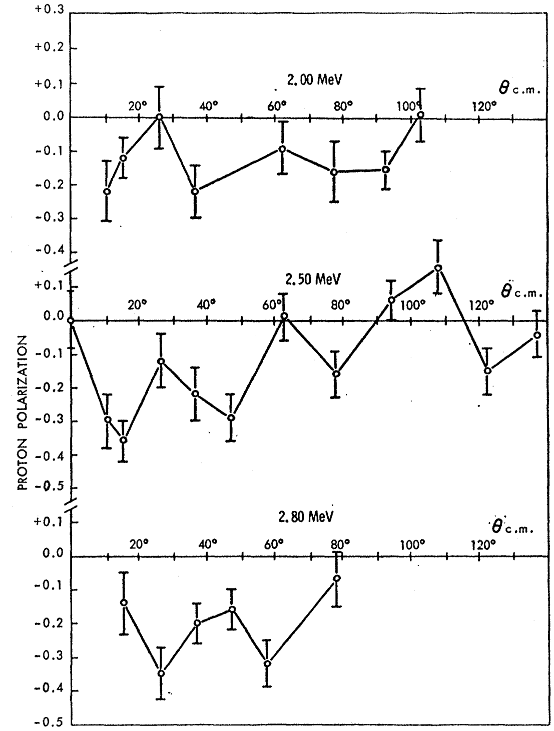

FIG. 1. Angular dependence of polarization of protons from the $B^{10}(He^3,p)C^{12}$(4.43 MeV) reaction at He^3 energies of 2.00, 2.50, and 2.80 MeV. The measurements at 2.50 and 2.80 MeV have been previously reported. The errors shown are counting errors only. Analyzing power of the polarimeter was taken at −0.50, where $\mathbf{k}_{in}\times\mathbf{k}_{out}$ is defined as positive.

III. RESULTS AND CONCLUSIONS

The angular distribution of the proton polarization from the $B^{10}(He^3,p)C^{12}$(4.43-MeV) reaction was measured at an incident He^3 beam energy of 2.00 MeV. Measurements were made at eight laboratory angles from 10° to 100°. In addition, measurements were made at 11 other selected angles at beam energies from 1.75 to 2.25 MeV. These results are given in Table I. The results at 2.00 MeV are shown in Fig. 1, along with those previously obtained at 2.50 and 2.80 MeV.[3] The sign of the polarization follows that of the Basel convention and is positive in the direction $\mathbf{k}_{in}\times\mathbf{k}_{out}$. As in the other measurements, the angular distribution at 2.00 MeV shows predominantly negative polarizations at laboratory angles forward of 90°.

The results of all the polarization measurements which have been made are given in the contour plot shown in Fig. 2. Here, since the polarization measurements have such large errors, regions within a range of polarizations are plotted in the $\theta_{c.m.}$ versus $E_{av}(He^3)$ plot. The lines shown are estimated to separate groupings of similar polarizations. The polarization ranges were obtained from the counting errors of the data points included in a particular region. The numbers shown in Fig. 2 give the measured polarization in percent at the datum point indicated by the nearest

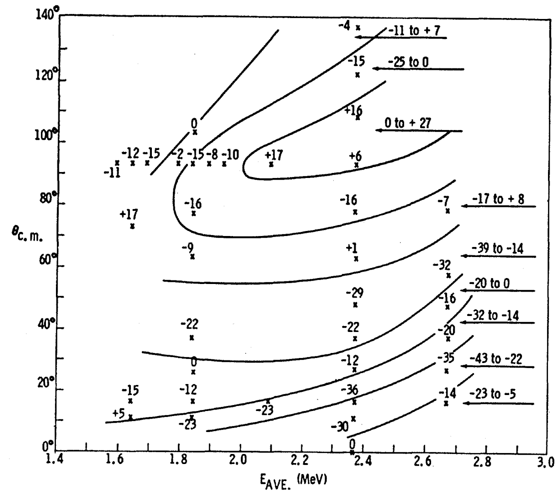

FIG. 2. Contour map of the polarization measurements for the $B^{10}(He^3,p)C^{12*}$(4.43-MeV) reaction. The contour lines separate broad regions of similar polarizations. The range of percentage of polarizations in each region is determined from the errors of the measured polarizations and is given by the numbers on the right. The experimental measurements are given in percent polarization and are plotted as crosses.

"x." Since thick targets were used (~250 to 300 keV), the abscissa chosen take into account the energy loss of the incident He^3 particles in the target. Thus, E_{av} is the He^3 energy at the half-thickness of the target. The dominant feature of this polarization plot shows that the energy dependence of the polarization is weak, particularly toward the forward angles.

Reaction Mechanism

The compound-nucleus interpretation by Schiffer *et al.*[4] was based mainly on excitation curve measurements. These curves showed a "resonance" peak at 2.0 MeV for protons emitted at laboratory angles of 0° but not 90°. This work also concluded that there was a possibility that more but narrower resonances could contribute to the reaction.

The completed polarization work reported here definitely shows a weak energy dependence in the region of the 2.0-MeV "resonance." This smooth variation of the polarization with energy is sufficiently demonstrated in the contour map of Fig. 2. The weak energy dependence is particularly dominant toward the forward direction, which is where the peak in the excitation curve occurs. Thus, if a "resonance" exists, it does not have a strong effect on the proton polarization.

The predominance of negative polarization throughout the forward angles where thick targets of the order of 250 to 300 keV are used rules out contributions to the reaction by more, but narrower, resonances. Measurements were made at a sufficiently large number of points with thick targets so that the energy range was almost completely covered. Any contributions due to rapid swings to positive polarizations, which would occur in a region of a narrower resonance, could not have been easily overlooked. If such were there, but were averaged out by the use of thick targets, smaller average polarizations would have been measured.

It is therefore concluded that a direct interaction is the best interpretation for the mechanism of this reaction for He^3 energies from 1.6 to 2.8 MeV. This mechanism is dominant in the forward directions. The "island" of positive polarizations, which appears at angles greater than 90° c.m. (see Fig. 2), may be due to compound-nucleus effects. This, however, would not be too surprising. If there were some compound-nucleus effects present, they would probably be more noticeable in the back angles.

It is difficult to arrive at a more definite conclusion about the existence of a broad resonance at 2.0 MeV without specific theoretical calculations on this reaction. The similarity of the energy dependence behavior of the proton polarizations from this reaction and from the $C^{12}(d,p)C^{13}$ reaction indicates that calculations similar to those made on the latter reaction should also be made here. Buck and Satchler[9] made calculations on the angular distributions and polarizations for the $C^{12}(d,p)C^{13}$ reaction which employed a superposition of compound nucleus and direct interaction effects in the region of the 4-MeV resonance. The results showed that the angular distributions and polarizations would exhibit a weak energy dependence near the resonance if the resonance was due to a single partial wave and there was also direct interaction interference due to many partial waves. Polarization measurements have recently been made to support their conclusion.[10]

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