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$A_{zz}(0°)$ for the charge-symmetric $^3He(\vec{d},p)^4He$ and $^3H(\vec{d},n)^4He$ reactions below 6.75 MeV

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The tensor analyzing power of $A_{zz}(0°)$ has been measured for the charge symmetric $^3He(d,p)^4He$ and $^3H(d,n)^4He$ reactions as a function of incident deuteron energy from 0.24 to 6.75 MeV. The measurements were performed in a nearly simultaneous fashion to ensure that a meaningful comparison of $A_{zz}(0°)$ for the two reactions could be made. The absolute scale of the $^3He(d,p)^4He$ analyzing power was calibrated at four energies using the isospin forbidden $^{16}O(d,\alpha_1)^{14}N$ reaction. Large differences in $A_{zz}(0°)$ for the two reactions were observed for energies both below 1.65 MeV and above 4 MeV. The $^3H(d,n)^4He$ data reported here resolve discrepancies in published data of other authors; the $^3He(d,p)^4He$ results confirm previously reported measurements, except for a small scale shift.

[NUCLEAR REACTIONS $^3He(\vec{d},p)^4He$, $^3H(\vec{d},n)^4He$, $E=0.24-6.75$ MeV; measured $A_{zz}(0°)$; calibrated beam polarization by $^{16}O(\vec{d},\alpha_1)^{14}N$ reaction.]

I. INTRODUCTION

Charge symmetry in the nuclear interaction is an important concept that is continually being tested in a myriad of ways. Because this symmetry can be broken by the electromagnetic interaction[1] of which the Coulomb interaction is the most likely, interest in these studies has focused on determining the mechanisms responsible for any breaking that may occur. Because the strength of the Coulomb interaction is weakest for the light mass nuclear systems, they provide a favorable way to explore symmetry breaking interactions.

In a recent comparison of vector and tensor analyzing powers in the charge symmetric reactions $^2H(\vec{d},n)^3He$ and $^2H(\vec{d},p)^3H$, Dries *et al.*[2] observed that there were substantial differences in the tensor analyzing powers for these two reactions. Their results showed that these differences could not be explained by simply including a Coulomb correction in an *ad hoc* fashion, as had been proposed[3] to explain differences in vector polarization data for these reactions. As there is presently no explanation[4] of the sizable differences that occur here, this remains as a challenging problem in understanding the four nucleon systems.

Because the measurements of the tensor analyzing power $A_{zz}(0°)$ so illuminated the differences in the 4-nucleon system, the same technique has been extended here to study the charge symmetric reactions for the 5-nucleon system, namely, the $^3He(d,p)^4He$ and $^3H(d,n)^4He$ reactions. Here, tensor polarization data available for comparing these reactions are scarce and subject to disagreement, particularly for the (d,n) reaction.[5-8] Some comparisons of polarizations and vector analyzing powers have been reported which show little difference[9] between the two reactions.

A second motivation for these measurements was related to our systematic studies of the structures of light nuclear systems. The energy level structure of the 5-nucleon system has generally been regarded as one of the simplest, with tabulations[10] citing the presence of only a few excited states. However, microscopic cluster model calculations[11] suggest that the structure of this system near 20 MeV may be considerably more complex, with predictions that there should be six positive parity states and a pair of negative parity states. The latter states are coupled to α^*, the first excited state of the alpha particle. The presence of some of these states has been signaled by experimental data.[12,13] Although the R-matrix calculations[4] suggest that at least some of these states may be present, the data base is presently inadequate to determine much about such structure. Adding to the analysis problems are ambiguities in the data from various laboratories.

Finally, a third motivation was to establish, at low energies in particular, $A_{zz}(0°)$ for the $^3He(d,p)^4He$ reaction as a secondary standard beam polarization monitor for our polarized deuteron experiments. The advantages of using this reaction as such a polarization monitor[14,15] are well known: the unusually high Q value makes proton detection experimentally attractive, the $A_{zz}(0°)$ are generally large at most energies and vary smoothly with energy, and the reaction has good yield so that a rapid measurement can be made. However, our concern is twofold. Polarized beams can become depolarized[16] in tandem accelerator terminals by residual gas interactions, a process that gets accentuated at low tandem accelerator voltages as the particles spend a greater percentage of their time in the region where the charge exchange can take place as a two-step process. Because the ^{3}He(d,p) reaction is so widely used for monitoring the beam polarization p_{zz}, it was considered essential that an independent measurement of A_{zz} be made, where the analyzing power can be calibrated on an absolute scale.

Thus, in this paper, we report the simultaneous measurement of the tensor analyzing powers $A_{zz}(0^\circ)$ for the charge symmetric reactions ^{3}He(d,p)^{4}He and ^{3}H(d,n)^{4}He over the 0.24 to 6.75 MeV energy range. The absolute scale of A_{zz} for the ^{3}He(d,p) reaction was determined using the isospin-forbidden ^{16}O(d,α_1)^{14}N reaction[17] at several deuteron energies.

II. EXPERIMENTAL METHOD

The polarized deuteron beam was provided by the Ohio State polarized ion source[18] which is installed inside the high voltage terminal of a 7 MV Van de Graaff accelerator. This ground state atomic beam source produces, for purposes of this experiment, beams with two different tensor polarization states that are equal in magnitude but opposite in sign, viz., $p_{zz} \simeq \pm 0.8$, and are produced with rf transitions which are virtually 100% efficient. Beam intensities on target ranged from 10 nA at 1 MeV to 100 nA at 6 MeV, the differences due to the better beamline transmission at higher energies.

In these experiments, the deuteron spin vector was always aligned parallel to the beam momentum vector at the reaction target using a spin precessor ($\vec{E} \times \vec{B}$ fields) in the polarized ion source. In this alignment, only the p_{zz} tensor moment of the beam is nonzero at the target. The cross section for a reaction induced by a polarized beam, whose spin is in this orientation, is then given by the very simple expression

$$\sigma(\theta) = \sigma_0(\theta)[1 + \tfrac{1}{2} p_{zz} A_{zz}(\theta)],$$

where $\sigma_0(\theta)$ is the cross section for an unpolarized beam and $A_{zz}(\theta)$ is the tensor analyzing power of the reaction under investigation.

For the special case of the ^{16}O(d,α_1)^{14}N reaction, Jacobsohn and Ryndin[17] have shown that $A_{zz} \equiv 1$ for all energies and angles. Then, in the above expression, only the beam polarization p_{zz} is unknown and hence it can be determined in an absolute way from ratios of yields measured for different beam polarization states. If a measurement of $A_{zz}(0^\circ)$ for the ^{3}He(d,p)^{4}He reaction is made as part of the same experiment, the absolute scale of A_{zz} for this latter reaction can also be determined, establishing it as a standard for monitoring beam polarizations. Below we discuss first our use of the ^{16}O(d,α_1) reaction to calibrate our beam polarization and then our measurement of $A_{zz}(0^\circ)$ for the charge symmetric ^{3}He(d,p) and ^{3}H(d,n) reactions.

A. Absolute calibration of the beam polarization using the ^{16}O($\vec{d},\alpha_1$)^{14}N reaction

Although the ^{16}O(d,α_1) reaction is useful in determining p_{zz}, the yields for this isospin-forbidden reaction are so low that measurements are nearly impossible, except at isolated energies and angles. For our determination, we selected mean deuteron energies of 3.85 and 5.72 MeV at $\theta_L = 50^\circ$ where $\sigma(50^\circ)$ rises[19] to ~1 mb/sr. A gas scattering chamber, equipped with a 1.3 μm thick nickel entrance window and a 2.5 μm thick Havar exit window contained the O_2 gas, where the distances from the entrance (exit) windows to the center of the chamber are 8.6 (13.6) cm. The gas pressures were selected as a compromise between reasonable counting rates and detection of the α_1 particles with good pulse height resolution, with the latter being the overriding consideration because of the backgrounds discussed below. The corresponding O_2 pressures were 0.08 atm at 3.85 MeV and 0.25 atm at 5.72 MeV, which limited the energy loss of the α_1 particles in traveling the 10 cm to the detectors to a modest 2 to 4 MeV. Charge integration of the incident beam was effected by a Faraday cage mounted beyond the exit window of the chamber. The above arrangement of using a gas scattering chamber proved far superior to our earlier attempts to use a gas target, even when the latter had a very thin exit window, since the energy straggle associated with the cell window sufficiently broadened the α_1 peak that it was difficult to detect with sufficient resolution for a reliable measurement, particularly at 3.85 MeV.

Detector telescopes, mounted both left and right of the beam axis at $\pm 50^\circ$, subtended half-angles of 10° to increase the counting rates. Several different detector arrangements were tried, with the best results obtained using telescopes consisting of a pair of totally depleted surface barrier detectors. The front detector was 15 μm thick, with an active area of 25 mm^2, while the rear detector was 50 μm and 50 mm^2. The latter was operated in anticoincidence with the front detector and was larger in area to ensure efficient rejection of unwanted counts. Here the α_1 group is stopped completely in the 15 μm detector, whereas the more energetic α_0 group loses only a fraction of its energy there, such that the α_0's appear in the pulse height spectrum as an intense peak lower in

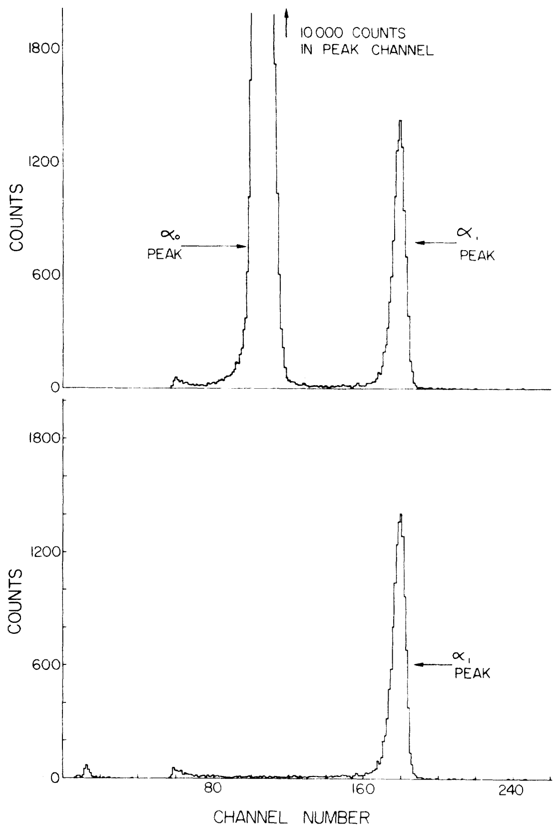

FIG. 1. The top panel of this figure shows a typical pulse height spectrum for the $^{16}O(d,\alpha_1)^{14}N$ reaction at 5.72 MeV as seen by the front (15 μm) detector of the telescope. Shown are the α_0 peak and the α_1 peak of interest. The bottom panel shows the same pulse height spectrum for this detector when gated in anticoincidence by the back (50 μm) detector, a technique that removed the α_0 peak completely from the spectrum.

pulse height than the α_1 group. This is illustrated in the top panel of Fig. 1. The bottom panel shows the same spectrum subject to the anticoincidence gate of the second detector. Here the α_0 group is completely eliminated, making the determination of the α_1 group intensity quite direct. A small low energy tail, essentially unpolarized, can then be subtracted off reliably. The latter averaged ~1.5% of the integrated α_1 counts, and differed slightly in the left and right detectors. This spectrum is considerably cleaner than is usually obtained in measurements of this type, where backgrounds of $\geq 10\%$ are not unusual. Computation of p_{zz} was done independently for the left and right detectors, yielding results that were in excellent agreement.

In order to calibrate the analyzing power of the considerably higher yield $^3He(d,p)$ reaction to establish it as a secondary polarization standard, measurements of $A_{zz}(0°)$ for the (d,p) reaction were interspersed with the (d,α_1) measurements. First, a ^3He polarimeter was mounted beyond the exit foil in the scattering chamber and a measurement simultaneous with the (d,α_1) measurement was made. This ^3He assembly also served as a faraday cage for charge normalization. Secondly, the gas scattering chamber was periodically evacuated and a ^3He polarimeter inserted into the center of the scattering chamber. In both cases, the ^3He gas was contained at 1.7 atm by a 2.5 μm thick Havar entrance foil, and a 0.25 mm thick tantalum exit window. The latter was thick enough to stop the beam for charge integration purposes, but thin enough to let the reaction protons pass through to a 1.5 mm thick partially depleted surface barrier detector located just behind the ^3He cell. Additional stopping foils were required directly in front of the detector to further slow the energetic protons so that they could be detected with good pulse height resolution. Because of the different foil thicknesses and gas pressures in the scattering chamber, measurements with the two ^3He polarimeters correspond to different mean E_D and hence yield calibrated values of A_{zz} for $^3He(d,p)$ at two separate energies for each accelerator energy.

The data were acquired in the following manner: With O_2 gas in the chamber, a data set of three runs was taken. These were runs with (1) $p_{zz} \simeq +0.8$, (2) unpolarized, and (3) $p_{zz} \simeq -0.8$. The polarization reversal was accomplished by effecting rf transitions in the polarized ion source. The quantity $p_{zz}A_{zz}$ can be calculated for each set in three separate ways, providing a consistency check on the data. The data acquisition phase of the polarization calibration required ~2 days/energy. In general, (d,α_1) spectra were recorded for ~10 minutes per polarization state. The scattering chamber was evacuated every 3 hours and the ^3He polarimeter inserted for the "in-chamber" $^3He(d,p)$ A_{zz} measurement. The beam polarization was determined to vary ≤ 0.01 over the 3 day duration of this experiment.

The overall value of p_{zz} was determined to be -0.7936 ± 0.0034 at 3.85 MeV and -0.7987 ± 0.0030 at 5.72 MeV, which are in excellent agreement. Further consistency is noted by the independent left and right detector measurements (which have different background corrections), which are respectively, at 3.85 MeV, -0.7957 ± 0.0048 and -0.7915 ± 0.0048 and at 5.72 MeV, -0.7998 ± 0.0043 and -0.8098 ± 0.0043. The values of A_{zz} for the $^3He(d,p)^4He$ reaction, calibrated by this beam, are listed in Table I, at the deuteron energies of 3.11, 3.80, 4.77, and 5.93 MeV, along with the other $^3He(d,p)$ data acquired, as discussed below.

TABLE I. Experimental values of $A_{zz}(0°)$ for the $^3He(d,p)^4He$ and $^3H(d,n)^4He$ reactions.

$^3He(d,p)^4He$ $\langle E_D \rangle$	$A_{zz} \pm \Delta A_{zz}$ [a]	$^3H(d,n)^4He$ $\langle E_D \rangle$	$A_{zz} \pm \Delta A_{zz}$ [a]
0.480 ± 0.060	−0.895 ± 0.012(0.004)	$0.240^{+0.180}_{-0.090}$	−0.929 ± 0.014(0.007)
0.760 ± 0.045	−0.784 ± 0.011(0.004)		
		$0.570^{+0.120}_{-0.090}$	−0.624 ± 0.011(0.008)
1.000 ± 0.040	−0.692 ± 0.011(0.005)		
1.250 ± 0.035	−0.644 ± 0.010(0.005)	$0.850^{+0.100}_{-0.090}$	−0.468 ± 0.010(0.008)
1.590 ± 0.025	−0.673 ± 0.010(0.005)		
1.740 ± 0.025	−0.711 ± 0.010(0.005)	1.140 ± 0.080	−0.413 ± 0.009(0.007)
2.060 ± 0.025	−0.805 ± 0.012(0.005)	1.490 ± 0.070	−0.498 ± 0.010(0.008)
2.250 ± 0.020	−0.886 ± 0.012(0.005)	1.650 ± 0.070	−0.544 ± 0.011(0.008)
2.530 ± 0.020	−1.024 ± 0.015(0.005)	1.970 ± 0.060	−0.734 ± 0.013(0.008)
2.750 ± 0.020	−1.134 ± 0.015(0.005)	2.170 ± 0.060	−0.839 ± 0.014(0.008)
3.020 ± 0.015	−1.250 ± 0.018(0.005)	2.460 ± 0.055	−0.994 ± 0.016(0.008)
3.114 ± 0.015 [b]	−1.326 ± 0.015(0.003)	2.680 ± 0.050	−1.148 ± 0.018(0.008)
3.250 ± 0.015	−1.348 ± 0.020(0.005)	2.960 ± 0.050	−1.267 ± 0.019(0.007)
3.520 ± 0.015	−1.456 ± 0.020(0.004)	3.190 ± 0.050	−1.350 ± 0.020(0.007)
3.795 ± 0.015 [b]	−1.542 ± 0.018(0.003)	3.460 ± 0.045	−1.414 ± 0.021(0.007)
4.020 ± 0.015	−1.590 ± 0.022(0.003)	3.740 ± 0.045	−1.485 ± 0.021(0.007)
4.250 ± 0.015	−1.636 ± 0.022(0.003)	3.960 ± 0.040	−1.516 ± 0.022(0.008)
4.510 ± 0.010	−1.673 ± 0.023(0.003)	4.010 ± 0.040	−1.556 ± 0.022(0.006)
4.750 ± 0.010	−1.710 ± 0.023(0.003)	4.200 ± 0.040	−1.557 ± 0.022(0.006)
4.768 ± 0.010 [b]	−1.685 ± 0.019(0.003)	4.460 ± 0.040	−1.582 ± 0.022(0.006)
5.010 ± 0.010	−1.723 ± 0.024(0.003)	4.700 ± 0.040	−1.567 ± 0.021(0.006)
5.250 ± 0.010	−1.743 ± 0.023(0.003)	4.960 ± 0.035	−1.591 ± 0.022(0.006)
5.510 ± 0.010	−1.733 ± 0.023(0.003)	5.030 ± 0.035	−1.616 ± 0.022(0.006)
5.750 ± 0.010	−1.762 ± 0.025(0.003)	5.210 ± 0.035	−1.584 ± 0.022(0.006)
5.925 ± 0.010 [b]	−1.733 ± 0.019(0.003)	5.460 ± 0.035	−1.579 ± 0.022(0.006)
6.010 ± 0.010	−1.746 ± 0.024(0.003)	5.710 ± 0.035	−1.538 ± 0.021(0.006)
6.135 ± 0.010	−1.741 ± 0.024(0.003)	5.970 ± 0.030	−1.536 ± 0.022(0.006)
6.390 ± 0.010	−1.724 ± 0.024(0.003)	6.040 ± 0.030	−1.569 ± 0.022(0.006)
6.640 ± 0.010	−1.695 ± 0.024(0.003)	6.250 ± 0.030	−1.546 ± 0.022(0.006)
		6.500 ± 0.030	−1.566 ± 0.022(0.006
		6.750 ± 0.030	−1.553 ± 0.022(0.006)

[a] The ΔA_{zz} are calculated with (without) the Δp_{zz} term, as discussed in the text.
[b] These values of A_{zz} were calibrated absolutely using the $^{16}O(d,\alpha_1)^{14}N$ reaction.

B. Measurement of $A_{zz}(0°)$ for the $^3He(\vec{d},p)^4He$ and $^3H(\vec{d},n)^4He$ reactions

Frequently, when comparisons of polarization-type data have been made between similar reactions, such as we have here, the data have been acquired at different laboratories and under sufficiently different experimental conditions that it becomes difficult to arrive at definite conclusions. To remove such uncertainties, we have measured A_{zz} for these charge symmetric reactions in a single experiment under comparable experimental conditions. For this, a special target was fabricated. The ^3He gas was contained by a 2.5 μm thick Havar entrance foil at a pressure of 1.7 atm in a cell that had a beam path length of 6.4 mm. The exit window of this cell consisted of a 0.25 mm thick platinum disk on which 0.9 mg/cm^2 of titanium had been evaporated and infused with tritium. The backing was thick enough to stop the deuteron beam for charge integration purposes, but thin enough to allow the highly energetic protons from the $^3He(d,p)^4He$ reaction ($Q = 18$ MeV) to pass into the air to a detector.

These (d,p) protons were detected by a 1.5 mm thick surface barrier detector mounted at 0° and collimated to subtend a half-angle of 4°. Because the A_{zz} angular distribution shape is known to be relatively flat[20] for $\theta < 10°$, this size angular acceptance will not introduce significant errors. The neutrons were detected using a 5 × 5 cm NE213 bubble-free scintillator mounted directly behind the proton detector. This scintillator, which also subtended a half-angle of 4°, allowed standard

n-γ discrimination techniques with an ORTEC 458 pulse shape analyzer module. The proton detector was removed for the (d,n) measurement to permit the nuetron flux to pass uninhibited to the neutron scintillator.

Pulse height spectra of the protons or neutrons were stored in an IBM-1800 on-line computer using a Tennelec PACE analog-to-digital converter (ADC). For the neutron measurements, the following spectra were stored: (1) the time spectrum from the ORTEC 458 pulse shape analyzer, (2) the latter spectrum gated for neutrons, (3) the linear recoil spectrum from the scintillator, and (4) the latter spectrum gated for neutrons. Spectra (1)–(3) served to determine the effectiveness of the n-γ discrimination; spectrum (4) was used in determining the analyzing power. For this, the recoil spectrum was divided into bins, where each bin corresponded to a pulse height that was some nominal percentage of the maximum recoil pulse height. The analyzing powers were computed as a function of these different bias levels to assess possible contributions from undetected backgrounds, incomplete n-γ separation, etc. In the final data determination, a conservative 80% of maximum pulse height was used as the lower limit for the integration of the number of counts in the pulse height spectrum, although insignificant changes in these values would have resulted with a lower choice of bias.

The data acquisition procedure was as outlined in the $^{16}O(d,\alpha_1)$ experiment, namely, a sequence of three runs formed a set to compute A_{zz}, which were: a $p_{zz} \cong +0.8$ run, an unpolarized run, and a $p_{zz} \cong -0.8$ run. The overspecification again allowed consistency checks to be made. In general, about 300 000 counts were acquired for each set for the (d,p) reaction, and about 130 000 counts for the (d,n) reaction using the conservative 80% bias level. A measurement of A_{zz} for the (d,p) reaction was followed by a (d,n) run, or vice versa. Thus the ratio of A_{zz} for the two reactions is independent of long term fluctuations in the beam polarization (if they had occurred) and is useful therefore in determining if differences in A_{zz} exist in the two data sets.

Because the nature of this experiment dictates that there is no suitable beam polarization monitor, several procedures were used to monitor the beam polarization during the course of these measurements. First, A_{zz} was periodically measured for the $^3He(d,p)$ reaction at $E_D = 3.80$ MeV, one of the data points calibrated by the $^{16}O(d,\alpha_1)$ reaction. Secondly, the data in the 1–4 MeV range were remeasured at every third energy. In no case was a change in p_{zz} outside statistical uncertainties (~0.01) detected.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental values of A_{zz} for these two reactions are given in Table I at the mean energies of measurement. Below 1 MeV, the rapid variation in the reaction cross sections necessitates a correction for the mean energy and results in the asymmetrical energy spread quoted in the table. The quoted energy uncertainty is the target "half-thickness." The accelerator energy is believed known to ± 0.015 MeV. The data has also been corrected for deadtime (< 2.5%) in the pulse height analyzer. Because the measurements of $p_{zz}A_{zz}$ for the reaction of interest and of p_{zz} using some polarization monitor are independent, the uncertainty in A_{zz} must be calculated using the expression

$$\Delta A_{zz} = A_{zz}\left[\left(\frac{\Delta p_{zz}A_{zz}}{p_{zz}A_{zz}}\right)^2 + \left(\frac{\Delta p_{zz}}{p_{zz}}\right)^2\right]^{1/2} .$$

In our case, the Δp_{zz} term includes the statistical uncertainty in the actual polarimeter measurement (± 0.003), the uncertainty in the analyzing power of the polarimeter as calibrated with the $^{16}O(d,\alpha_1)$ reaction (± 0.008), the charge normalization uncertainty (± 0.005), and the uncertainty contribution from beam spin alignment (±0.003), which when combined in quadrature yields $\Delta p_{zz} = \pm 0.010$. It is important to note that the Δp_{zz} term can dominate the overall uncertainty ΔA_{zz} when A_{zz} is large, as it is in this experiment. The dominance of the second term can be seen in Table I where the uncertainty is calculated in two ways: The first is carried out using the above expression, and the second, quoted in parentheses, represents an uncertainty where the Δp_{zz} term has been ignored. Some authors have quoted only a statistical uncertainty in their tabulations of comparable data, and have not included the Δp_{zz} contribution explicity. Hence care must be exercised in comparing the data from different sources and in using such results for a polarization monitor. This also serves to illustrate the difficulty in establishing a good monitor for deuteron polarization that is accurately known, and rapid and convenient to use.

The results for the $^3He(d,p)$ reaction are plotted in Fig. 2, together with comparable data of other authors.[21-23] It is seen that A_{zz} is quite large over the whole energy range spanned, and varies slowly with energy. These characteristics, combined with the large reaction cross section and the very high Q value make this an excellent tensor polarization monitor. In general, our results agree with Schmelzbach *et al.*,[21] except that our results are systematically lower in magnitude by 2–4% of the measured values. This difference would

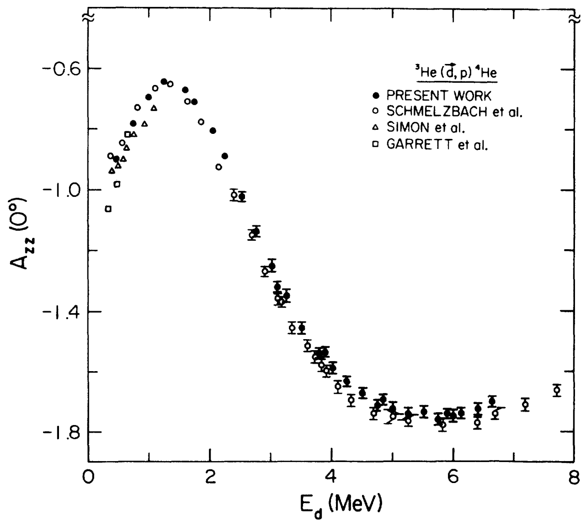

FIG. 2. Comparison of A_{zz} (0°) for the ^{3}He$(d,p)^4$He reaction with the data of other authors (Refs. 21–23). The error bars for the data of Schmelzbach *et al.* (Ref. 21) have been recalculated to include the Δp_{zz} contribution as described in the text.

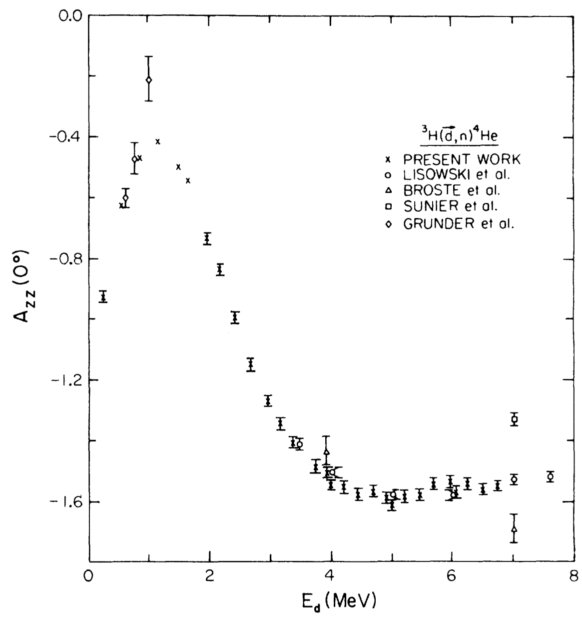

FIG. 3. Comparison of A_{zz} (0°) for the ^{3}H$(d,n)^4$He reaction with the data of other authors (Refs. 5–8). The large discrepancies in the values of A_{zz} (0°) at 7 MeV have been resolved in favor of Lisowski *et al.*

appear to be due to the determination of p_{zz} using the ^{16}O(d,α_1) reaction and its subsequent effect on the absolute value of A_{zz}. Background contributions to our α_1 spectra were considerably lower than occurred in their work, leading us to have confidence in our results. Below 2 MeV, our results agree with other authors,[22,23] except for a few points. Although Grüebler *et al.*[14] and König *et al.*[15] also report measurements, these are superseded by the data of Schmelzbach *et al.*[21] from the same laboratory. Data of Trainor *et al.*[24] just overlap, and agree with, our highest energy data.

Our A_{zz} data for the ^{3}H(d,n) reaction are plotted in Fig. 3 and compared with data of other authors.[5-8] The rather obvious discrepancy between the three previously reported data points at 7 MeV appears to be resolved in favor of Lisowski *et al.*[5] by our work. Our measurements, and those of Lisowski *et al.* show that the early measurement of Broste *et al.*[8] at 4 MeV is too low in magnitude, opposite to their corresponding point at 7 MeV. At $E_D < 1$ MeV, we have used the Legendre polynomial coefficients for A_{zz} given by Grunder *et al.*[6] to calculate at 0° the value shown. The disagreement at 1 MeV suggests some problems may exist with their angular distribution at this energy.

IV. COMPARISON OF A_{zz} FOR THE ^{3}He$(\vec{d},p)$ AND ^{3}H$(\vec{d},n)$ REACTIONS

A comparison of our data for these two charge symmetric reactions is presented in Fig. 4. Here it is obvious that significant differences do occur in the two reactions in several energy regions and further that A_{zz} is always larger for the (d,p) reaction than for the (d,n) reaction. This is the same situation that occurred for A_{zz} for the ^{2}H(d,n) and

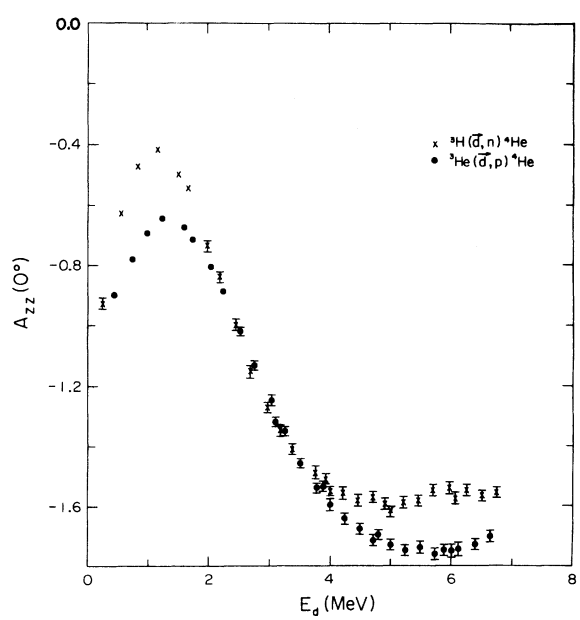

FIG. 4. Comparison of the present A_{zz} (0°) data for the charge symmetric ^{3}He$(d,p)^4$He and ^{3}H$(d,n)^4$He reactions illustrating the sizable differences that occur both below 1.65 MeV and also above 4 MeV.

$^2H(d,p)$ reactions, as reported earlier by Dries *et al.*[2]

The differences near 1 MeV are perhaps not so unexpected as there are slight differences in the mass-energy of these systems, and one may anticipate that the Coulomb interaction, which can break charge symmetry in the nuclear interaction, will have some effect at such low energies. In particular, the low energy region of both reactions here is dominated by a single $\frac{3}{2}^+$ state. However, this state appears as a resonance in the $^3H(d,n)$ reaction at 107 keV, but at 430 keV in the $^3He(d,p)$ reaction.

One anticipates that effects due to mass differences and the Coulomb interaction might be lessened at higher energies. Indeed, one observes that A_{zz} is essentially identical for the two reactions at energies between 2 and 4 MeV. Above that energy, however, substantial differences in A_{zz} reappear, differences that persist to near 8 MeV. No explanation of the origin of these differences is yet at hand. It is interesting to note that the differences occur in the energy region where the microscopic cluster model calculations[11] predict a number of states not yet identified. To determine if an accounting of these differences can be had, charge independent R-matrix calculations are being initiated at Los Alamos.[4] In addition to the usual compound nuclear states, a number of "background" states, particularly states of higher angular momenta, are included as a way of simulating[25] contributions from any competing direct reaction processes. While the latter procedure is not exact, it is the most feasible way to pursue the question at this time. It could determine whether violations of charge symmetry are plausible and pave the way for future exact, though difficult, microscopic calculations that would be required to settle this interesting issue.

What is clear, in any case, is that there are real differences in A_{zz} between the two reactions, an observation similar to what had been observed earlier in the 4-nucleon system. Such differences must be explained if we are to understand these light nuclear systems.

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