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Proton Polarization in the Reaction ^{40}Ca(d, p)^{41}Ca†

C. T. KELLEY, JR.,* W. E. MADDOX,‡ AND D. W. MILLER
Department of Physics, Indiana University, Bloomington, Indiana 47401

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The polarizations of protons from the reactions ^{40}Ca(d, p)^{41}Ca leading to the ground state and the 1.95- and 2.47-MeV excited states of ^{41}Ca have been measured at 13 angles between 30° and 148° in the laboratory system at a bombarding energy $E_d = 10.8$ MeV. A carbon polarimeter using solid-state detectors permitted the measurements for all three proton groups to be made simultaneously. The polarization results for the $l_n=3, j_n=\frac{7}{2}$ ground-state reaction are in good agreement with previous measurements, but extend to larger angles. Shapes of the polarization angular distributions for protons from the $l_n=1, j_n=\frac{3}{2}$ reactions exciting the 1.95- and 2.47-MeV states are very similar to each other except possibly near 100°. Comparisons are made with available theoretical predictions for these reactions.

I. INTRODUCTION

RENEWED interest in nuclear stripping reactions has resulted from recent theoretical and experimental developments, as summarized at the beginning of the preceding paper.[1] These include new theoretical approaches [the weakly bound projectile (WBP) model,[2] and the BHMM model[3,4]], refinements to the distorted-wave Born-approximation (DWBA) method,[5] and experimental measurements of polarization effects using polarized ion sources.[6–8] Although experiments of the present type using unpolarized beams normally provide results with poorer statistical accuracy than studies using polarized sources, they remain the only method at present for obtaining (d, p) polarization results for reactions in which the residual nucleus is unstable, and for reactions leading to several states of the same residual nucleus corresponding to different values of the orbital (l_n) and total (j_n) angular momentum transfer. The purpose of the present work was to measure simultaneously the polarizations of protons from the reactions ^{40}Ca(d, p)^{41}Ca leading to the ground, 1.95-, and 2.47-MeV states of ^{41}Ca over the angular region from 30° to 148° in the laboratory system.

In addition to numerous theoretical studies, the reaction ^{40}Ca(d, p)^{41}Ca has been extensively investigated experimentally. The (d, p) differential cross sections corresponding to excitation of the ground, 1.95-, and 2.47-MeV levels in ^{41}Ca, and the elastic (d, d) differential cross sections, have been measured at a number of bombarding energies including that of the present investigation.[9–11]

Ground-state proton polarizations have also been determined at several energies.[12–17] The polarizations of protons exciting the 1.95- and 2.47-MeV states in ^{41}Ca have been measured in the forward direction only at $E_d = 15$ MeV.[18] Foster *et al.*[11] have obtained the polarizations of protons exciting the 3.95-MeV state of ^{41}Ca over the angular region of the j-dependent minimum in the differential cross section.[19] Vector analyzing powers have also been measured[7] at forward angles using 7-MeV polarized deuterons to initiate (d, p) reactions exciting the ground, 1.95-, 2.47-, and 3.95-MeV states of ^{41}Ca.

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* Present address: Analytic Services, Inc., Falls Church, Va.
‡ Present address: Murray State University, Murray, Ky.

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II. EXPERIMENTAL METHOD

A. Apparatus

The apparatus, detectors, and electronics employed in this work have been described in the previous paper,[1] and only minor differences need be reported here. In this experiment, the deuteron beam current on target was in excess of 8 μA, and a much larger number of neutrons and γ rays were produced by the beam striking the slits and Faraday cup. The neutron radiation trebled when the deuteron beam was allowed to strike the thick calcium target. To reduce the effects of this radiation, a cylinder of lead and boron-paraffin mixture was placed around the end of the Faraday pipe, and concrete walls and water tanks were built around the Faraday pipe up to the scattering chamber. The detectors were shielded against γ rays by placing lead bricks around the polarimeter and by wrapping parts of the beam pipe with lead sheets. This shielding cut down on the background considerably, but did not eliminate the need to record background runs. The general radiation level also caused steady deterioration of the resolution of the thick solid-state detectors until the proton group exciting the 2.47-MeV state of ^{41}Ca appeared as a shoulder on the larger group exciting the 1.95-MeV state. This effect complicated the analysis of the data for these two states.

The calcium target used in this experiment was rolled from natural calcium metal to an approximate thickness of 3.9 mg/cm^2 while immersed in mineral oil, and then cleaned with petroleum ether before being placed in the scattering chamber. The carbon second scatterers were the same as those used in the experiment described in the preceding paper.

B. Experimental Procedures

Since the energies of the proton groups from the reaction $^{40}Ca(d,p)^{41}Ca$ initiated by 10.8-MeV deuterons do not change rapidly as a function of the laboratory observation angle, it was only necessary to set up the electronics for three angular ranges: 30°–60°, 70°–100°, and 110°–148°, inclusive. The procedure employed was to place the side-counter telescopes alternately in the center position of the polarimeter, and replace the carbon second scatterer with another carbon foil chosen so that the mean energies of the proton groups when viewed straight ahead were the same as the mean energies of the proton groups elastically scattered from the carbon analyzer at 45° during a polarization run. In this way a reasonable counting rate was available for adjusting the timing of the fast-slow coincidence circuits and the base lines and window widths; these settings were chosen to be wide enough that the proton groups were passed by the linear gate at any desired angle in the angular range.

During the actual polarization runs, the polarimeter was frequently rotated 180° about an axis passing through the centers of the first and second scatterers. This completely interchanged the roles of the detectors and electronics on the right side with those of the left side, and gave a direct measurement of the intrinsic asymmetry. Runs in each orientation were chosen to last about 1 h. The number of runs at each laboratory angle was determined by the criterion that a total of 2000 signal counts be obtained in the proton groups corresponding to the 1.95- and 2.47-MeV states in ^{41}Ca when added together (the only exceptions were at angles of 140° and 148° where the differential cross sections were quite small).

Since the Q value of the reaction $^{40}Ca(d,p)^{41}Ca$ is +6.21 MeV, the energies of the proton groups of interest were well above most of the background. However, two background runs, one in each polarimeter orientation, were taken at each angle following the procedure described in the previous paper. The duration of a background run (determined by integrated beam charge) was chosen to be about 10% of the duration of a signal run, based on the effect of each on the statistical error in the final result.

C. Data Analysis

1. *Fitting Procedure*

Data analysis was carried out on the Indiana University CDC coupled 3600/3400 computer. At each polarimeter angle θ_p, the data consisted of one background run and a number of signal runs for both the right and left counters in both polarimeter orientations.[1] Signal runs in each polarimeter orientation were added together at each polarimeter angle. Background runs were normalized to the signal runs by comparison of integrated beam charge per run, fitted with an exponential curve, and subtracted from the appropriate summed signal spectra. Examples of the spectra obtained in this way are shown by the dots in Fig. 1, after the dashed exponential background curves fitted over the region of interest had been subtracted. Note that background would have had a really significant effect only on the proton group corresponding to the 3.95-MeV state of ^{41}Ca, which for reasons to be discussed later is not reported in this work.

Each spectrum that resulted from subtracting the background was fitted simultaneously with a second exponential curve (representing contributions from small overlapping groups and from deuteron break-up) and four Gaussian curves for the four proton groups corresponding to the ground, 1.95-, 2.47-, and 3.95-MeV states of ^{41}Ca. The fitting procedure was done in two steps. First, one fit was attempted with all the parameters allowed to vary. This fit would yield realistic values for the width of the ground-state proton group,

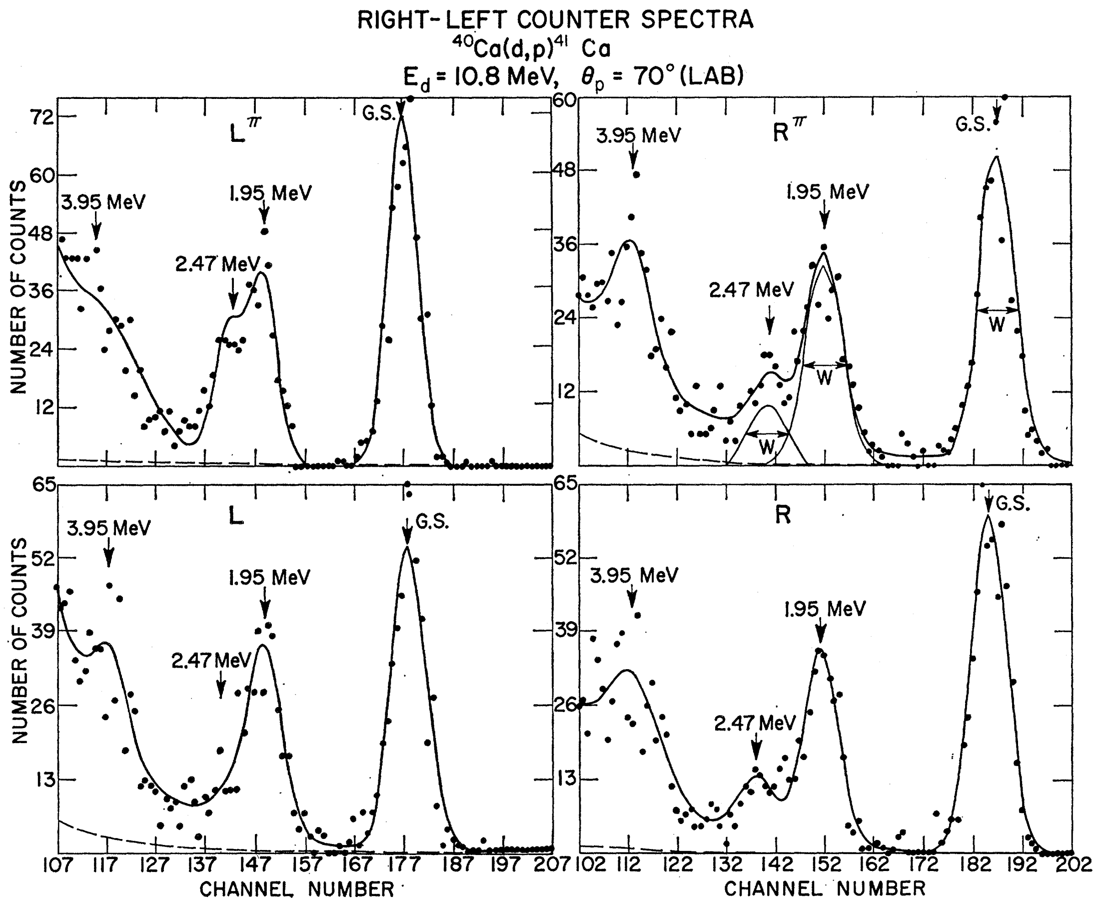

FIG. 1. Typical polarization spectra obtained by summing all of the polarization runs at one laboratory observation angle, in this case $\theta_p = 70°$. R represents the spectrum of particles scattered right-right and L the spectrum of particles scattered right-left into the right and left detectors, respectively, with the polarimeter in its normal position. L^π and R^π are spectra obtained with the same detectors rotated 180°, and correspond to particles scattered right-right and right-left, respectively. The solid curves are computer fits to the data, and the dashed curves show the magnitude of the background already subtracted in these plots.

the position of the ground-state group, and the position of the 1.95-MeV-level proton group. Then the widths of the 1.95- and 2.47-MeV groups would be set equal to that of the ground-state group, and the position of the 2.47-MeV-level group fixed relative to the 1.95-MeV-level group according to kinematics and the number of channels between the ground-state and 1.95-MeV-level groups. Final fits would then be made with all peak positions and widths held fixed. The resulting areas under the Gaussian curves were then considered to be the number of counts in the proton groups. The solid curves in Fig. 1 show the results of these procedures for one laboratory angle for the right and left counters at the two polarimeter orientations. One of the spectra shows the fitted curve over the 1.95- and 2.47-MeV groups broken down into two peaks, and indicates the width W used for all the groups in that spectrum.

There will be some error in the determination of the polarizations due to the uncertainties in the fitting procedure. In order to determine how sensitive the results were to this adjustment of peak parameters, at one angle the position of the peak corresponding to the 2.47-MeV state was shifted two channels and the width increased one channel for the right-counter spectrum only. When the product polarization was recalculated, the result deviated by less than 1% from the previous calculation where the peak parameters were assumed correct. Further details of the fitting procedures can be found elsewhere.[20]

2. Corrections

If there were no instrumental asymmetries, the product (P) of the polarization (P_1) of the protons produced in the initial reaction and the analyzing power

[20] C. T. Kelley, Jr., Ph.D. thesis, Indiana University, 1968 (unpublished), available from University Microfilms, 300 N. Zeeb Road, Ann Arbor, Mich. 48106.

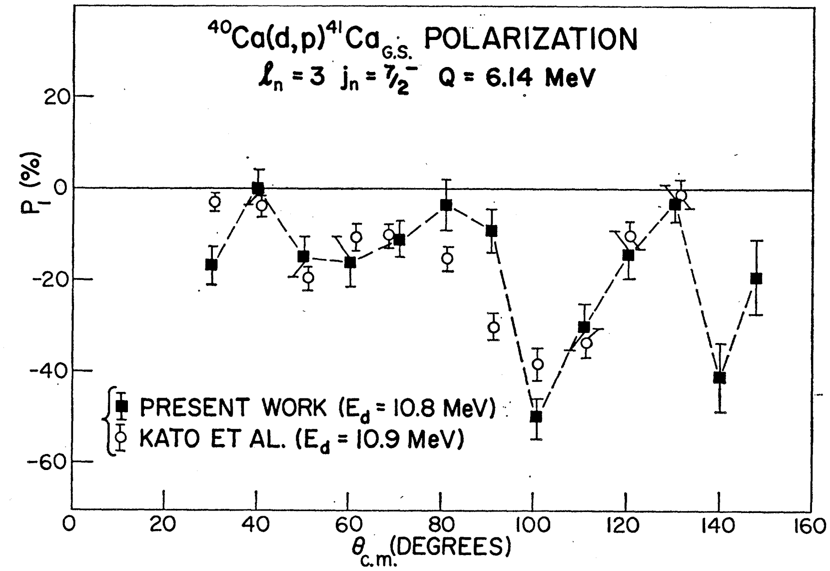

FIG. 2. Proton polarization results for the $l_n=3$, $j_n=\frac{7}{2}$ ground-state reaction $^{40}Ca(d,p)^{41}Ca$. Errors shown are statistical errors only. The dashed straight lines connecting data points serve only as a guide to the eye, and have no other signficance. The results of Kato *et al.* (Ref. 16) are shown for comparison.

(P_2) of the carbon polarimeter would simply be

$$P(\theta_p)=P_1P_2=\frac{(R+L^\pi)-(L+R^\pi)}{R+L^\pi+L+R^\pi}, \tag{1}$$

where R and L refer to integrated counts in the right and left detectors in their normal positions, and the superscript π refers to counts obtained with the same detectors rotated 180°. This must be corrected for any intrinsic asymmetry in the polarimeter, here defined by

$$K=\left(\frac{R}{L}\right)^{1/2}\Big/\left(\frac{L^\pi}{R^\pi}\right)^{1/2}. \tag{2}$$

In addition to the intrinsic asymmetry of the polarimeter, there is another asymmetry (K_σ) depending upon the horizontal intensity distribution of the deuteron beam spot on the calcium target, the $^{40}Ca(d,p)^{41}Ca$ differential cross section, the $^{12}C(p,p)^{12}C$ elastic differential cross section, and the sizes of the finite apertures. Thus, the actual "corrected" product polarization is given by

$$P^c(\theta_p)=\frac{(R-R^\pi)-KK_\sigma(L-L^\pi)}{R+R^\pi+KK_\sigma(L+L^\pi)}. \tag{3}$$

The polarization of protons from the (d,p) reaction is finally related to the corrected product polarization by

$$P_1(E_d,\theta_p)=P^c(\theta_p)/P_2^{\text{eff}}, \tag{4}$$

where P_2^{eff} is the analyzing power of carbon averaged over the energies and angles represented by the finite target thickness and finite solid-angle acceptances of the actual second-scatterer system, as described in the previous paper.[1] Figure 5 of that paper shows a plot of the resulting effective analyzing power of the polarimeter versus the proton energy incident on the second scatterer.

When calcium is bombarded by 10.8-MeV deuterons, a large number of deuterons from elastic (d,d) scattering are observed in the forward direction. These scattered deuterons can produce (d,p) reactions in the carbon second scatterer, and the resulting protons cannot be distinguished from protons from the reaction $^{40}Ca(d,p)^{41}Ca$ elastically scattered from the carbon, except possibly by their energy. Thus in the polarization spectra, the proton group exciting the 3.95-MeV level of ^{41}Ca appeared on top or near the proton group from the reaction [$^{40}Ca(d,d)$, $^{12}C(d,p)$] at angles forward of 70°; polarization results for this group were therefore fragmentary and are not reported. It should be noted that provision had been

TABLE I. Results of proton polarization measurements for the reactions $^{40}Ca(d,p)^{41}Ca$ leading to the ground, 1.95-, and 2.47-MeV states of ^{41}Ca at an incident deuteron energy of 10.8 MeV.

θ_{lab} (deg)	Proton polarization (P_1) Ground	1.95 MeV	2.47 MeV
29.4	−0.169±0.038	+0.090±0.040	+0.010±0.068
39.4	−0.000±0.040	−0.042±0.042	−0.351±0.074
49.4	−0.147±0.045	−0.039±0.038	+0.066±0.058
59.4	−0.162±0.054	+0.338±0.006	+0.414±0.088
69.4	−0.111±0.042	+0.052±0.058	−0.502±0.100
79.4	−0.034±0.056	−0.146±0.072	−0.191±0.109
89.4	−0.087±0.044	+0.070±0.054	−0.190±0.080
99.4	−0.502±0.044	+0.088±0.057	−0.444±0.108
109.4	−0.303±0.051	+0.045±0.074	−0.163±0.087
119.4	−0.143±0.048	−0.151±0.064	−0.315±0.107
129.4	−0.026±0.044	−0.254±0.062	−0.347±0.079
139.4	−0.410±0.074	−0.197±0.093	−0.240±0.121
147.4	−0.190±0.078	+0.062±0.079	+0.092±0.110

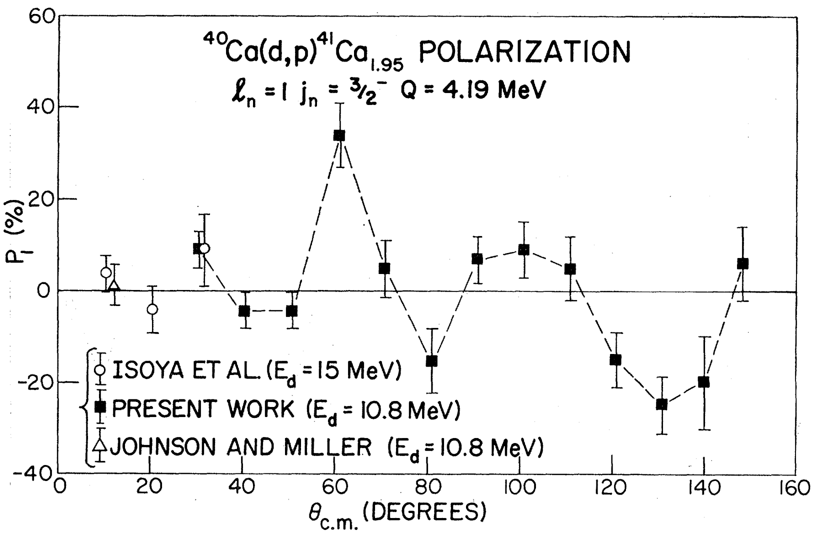

FIG. 3. Proton polarization results for the $l_n=1$, $j_n=\frac{3}{2}$ reaction ^{40}Ca(d, p)^{41}Ca leading to the 1.95-MeV excited state of ^{41}Ca. Symbols are explained in the caption of Fig. 2. Results of Isoya *et al.* (Ref. 18) and Johnson and Miller (Ref. 25) at forward angles are shown for comparison.

made in the target-chamber–polarimeter assembly to insert a solid-state transmission detector between the first and second scatterers in order to discriminate against pulses due to the elastically scattered deuterons. The counting rate in this transmission detector in a typical case was of the order of 10^6–10^7 counts/sec, however, and the electronics necessary to handle this large counting rate was not available at the time of this experiment.

III. EXPERIMENTAL RESULTS

A summary of (d, p) polarization results obtained in the present investigation is given in Table I. Errors quoted for the polarizations are statistical errors only.[1] Complete tables listing the c.m. angles, asymmetries, product polarizations, and values of P_2^{eff} for each group at each angle are on file with the American Society for Information Science.[21] Differential cross sections for the same reactions previously measured at about the same energy at this laboratory have been published earlier.[11]

Figure 2 shows the agreement between the present results for P_1 for the ground-state reaction ^{40}Ca(d, p)^{41}Ca at $E_d=10.8$ MeV and the data of Kato *et al.*[16] at $E_d=10.9$ MeV. The results of other experiments at nearby bombarding energies by Bercaw and Shull[15] at

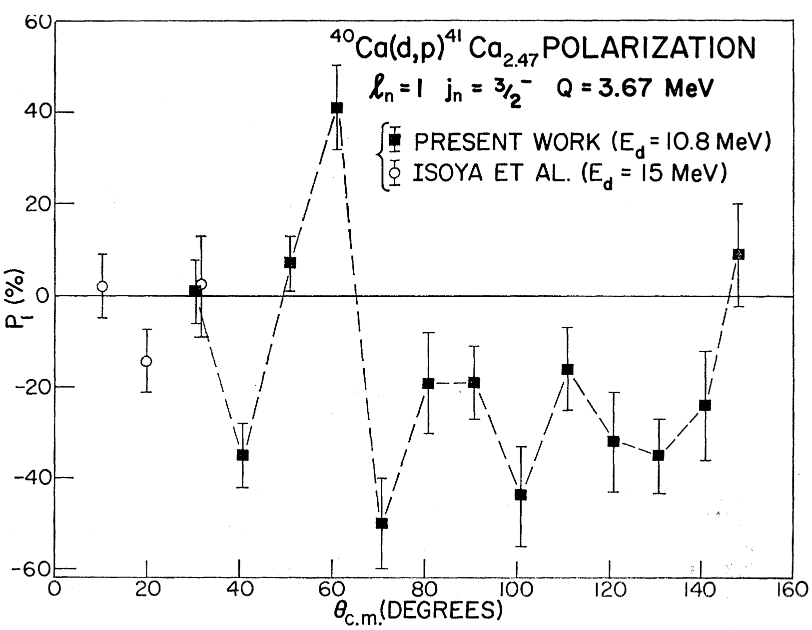

FIG. 4. Proton polarization results for the $l_n=1$, $j_n=\frac{3}{2}$ reaction ^{40}Ca(d, p)^{41}Ca leading to the 2.47-MeV excited state of ^{41}Ca. Symbols are explained in the caption of Fig. 2. The results of Isoya *et al.* (Ref. 18) at forward angles are shown for comparison.

[21] Order NAPS Document 00736 from ASIS National Auxiliary Publications Service, c/o CCM Information Sciences, Inc., 22 West 34th Street, New York, N.Y. 10001; remit $1.00 for microfiche or $3.00 for photocopy.

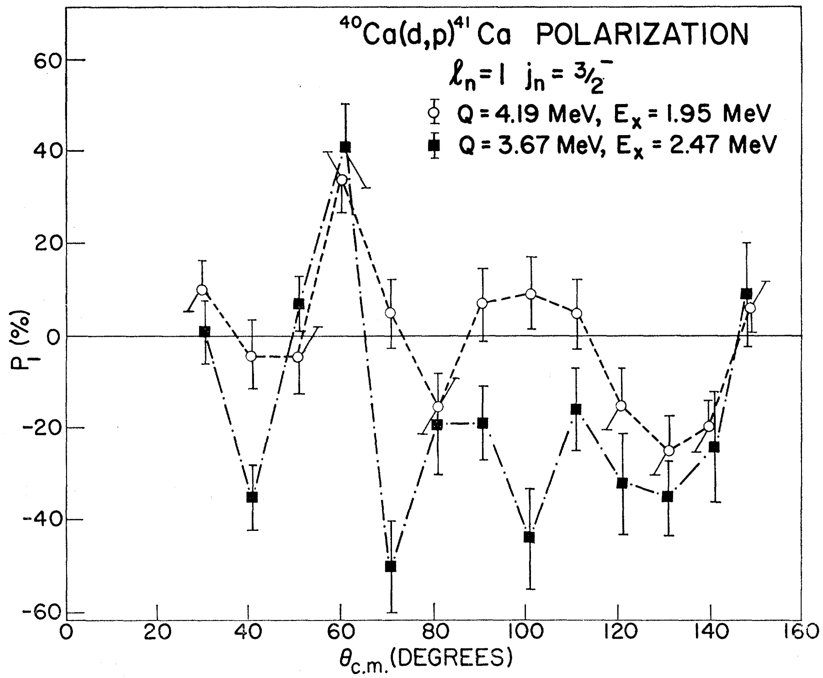

FIG. 5. The dashed curves shown in Figs. 3 and 4 for the polarizations of protons from the reactions ^{40}Ca(d, p)^{41}Ca leading to the 1.95- and 2.47-MeV excited states of ^{41}Ca reproduced together for comparison.

E_d = 10 MeV and Takeda *et al.*[12] at 11.4 MeV are very similar, except the 11.4-MeV results suggest a more pronounced dip near 70°. Although two of these earlier measurements extend in the backward direction to 130°, they give no hint of the additional dip in the polarization observed in the present investigation at 140°. There is no apparent correlation in the present results between oscillations in the polarization and the differential cross section.[11] Although $j_n = l_n + \frac{1}{2}$, the polarization is negative in the vicinity of the stripping peak in contradiction to the early "sign rule".[22,23] However, it is rather small in this region, in agreement with the regularity observed by Reber and Saladin[24] that $j_n = l_n - \frac{1}{2}$ transitions show large negative polarizations at small angles, while $j_n = l_n + \frac{1}{2}$ transitions exhibit small polarizations.

The proton polarizations for the reactions ^{40}Ca(d, p)^{41}Ca leading to the 1.95- and 2.47-MeV states have been measured previously only in the very forward direction at E_d = 15 MeV by Isoya, Micheletti, and Reber[18] and at E_d = 10.8 MeV by Johnson and Miller.[25] The earlier data are compared with the present results in Figs. 3 and 4. In these two reactions the orbital and total angular momenta transferred to the residual nucleus are the same (l_n = 1, $j_n = \frac{3}{2}$). Since the energy separation between the states is small (520 keV), one expects the (d, p) differential cross sections to have similar shapes. This has been verified experimentally,[10,11] and the magnitudes have also been found to be comparable (within a factor of about 2.5). One also expects the shapes of the proton polarization angular distributions to be similar, with perhaps different magnitudes. If one compares the curves in Fig. 5, which plots the dashed curves of Figs. 3 and 4 together, this intuitive prediction is found to be roughly correct. Up to 80° both curves oscillate about zero polarization with the curve corresponding to the 1.95-MeV level shifted slightly toward backward angles, as shown previously up to 30° by Isoya *et al.*[18] Beyond 120° the curves are again similar in shape. A possible anomalous behavior exists in the 90°–110° region where an additional dip in the polarization may be suggested for the group exciting the 2.47-MeV state; however, this group was not well resolved in this region due to counter deterioration, and firm conclusions are not possible. If the effect were confirmed,[26] it would be interesting to note that this is the same angular region in which the differential cross section for the l_n = 1, $j_n = \frac{1}{2}$ reaction ^{40}Ca(d, p)^{41}Ca exciting the 3.95-MeV state exhibits a large minimum,[19] which was also originally unexpected.

There does appear to be a correlation between the polarization curves and the (d, p) differential cross sections for the reactions exciting the 1.95- and 2.47-MeV levels, in that the zeros in the polarization occur near the maxima and minima in the differential cross sections. However, the sign of the polarization is op-

[22] W. Tobocman, *Theory of Direct Nuclear Reactions* (Oxford University Press, London, 1961).

[23] C. A. Pearson, J. M. Bang, and L. Pocs, Ann. Phys. (N.Y.) **52**, 33 (1969).

[24] L. H. Reber and J. X. Saladin, Phys. Rev. **133**, B1155 (1964).

[25] W. P. Johnson and D. W. Miller, Phys. Rev. **124**, 1190 (1961).

[26] Another check would be the l_n = 1, $j_n = \frac{3}{2}$ reactions ^{52}Cr(d, p)^{53}Cr to the 2.32- and 3.61-MeV states of ^{53}Cr.

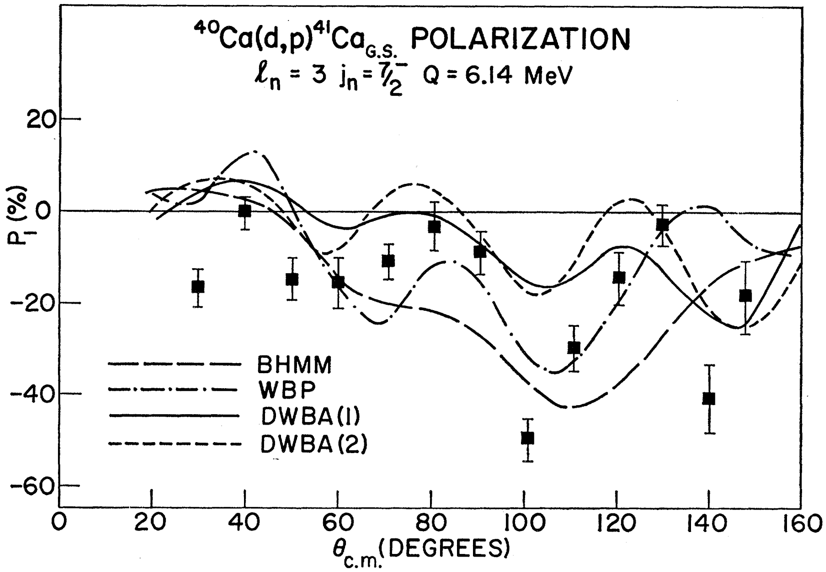

FIG. 6. Present results for the proton polarizations produced in the ground-state reaction ^{40}Ca$(d, p)^{41}$Ca (indicated by the black squares) compared with specific theoretical predictions of the BHMM, WBP, and DWBA models of the reaction described in the text.

posite to that predicted by the "derivative rule."[27] This "rule" may have some empirical validity for $l_n=0$ transitions beyond about 50°,[1,28] but was never expected to apply to $l_n\neq 0$ reactions such as those under study here.

As a final comparison, Bjorkholm, Haeberli, and Mayer[8] have measured with good statistical accuracy the analyzing power for the reaction ^{53}Cr$(p, d)^{52}$Cr using incident polarized protons, which is equivalent to measuring the proton polarization in the reaction ^{52}Cr$(d, p)^{53}$Cr. This reaction has the same orbital and total angular momentum transfers and very roughly the same target mass number as the two excited-state reactions studied here. A comparison of Fig. 3 with the experimental results of Bjorkholm *et al.* shows rather good qualitative agreement in shape, with some differences in magnitudes. In addition, the DWBA fit they show rises at back angles beyond their measured points; a similar rise is observed in the present work at the back angles.

IV. DISCUSSION

It was not feasible during this investigation to try to fit the results theoretically. However, DWBA calculations for two of the polarization angular distributions reported here have been made by Schwandt and Haeberli,[29,30] and theoretical predictions for the ground-state reaction using the BHMM and WBP theories have been published earlier.

Figure 6 shows a comparison of the experimental results of this investigation for the ground-state reaction ^{40}Ca$(d, p)^{41}$Ca with the theoretical predictions. The four curves shown in the figure result from the following calculations. (a) The curve labeled BHMM (long dashes) shows the prediction of May and Truelove[4] for a deuteron energy $E_d=10.9$ MeV using the BHMM model and the proton and neutron optical potentials of Rosen *et al.*[31] (b) The curve labeled WBP (dash dot dash) is a prediction by Pearson, Bang, and Pocs[23] for $E_d=10.9$ MeV using the WBP model and Rosen parameters for the proton but with a more strongly absorbing neutron potential (parameter set *C* of Ref. 23). (c) The solid curve labeled DWBA (1) shows a DWBA prediction by Schwandt and Haeberli[29] for $E_d=11$ MeV. This curve employed deuteron parameters that gave the best fit to elastic deuteron scattering cross section and polarization data (Table 2 of Ref. 29) and proton parameters of Greenlees and Pyle[32] specified in Table 3 of Ref. 29. (d) The curve labeled DWBA (2) (short dashes) is a DWBA fit by Schwandt,[30] using the same deuteron potential but with proton parameters adjusted to give a better fit to the present (d, p) polarization results.

None of the theoretical predictions agree well with the data. The DWBA calculations do show the proper trend, and the maxima and minima of the theoretical fits appear at about the correct c.m. angles. However, the experimental data indicate wider oscillations and different magnitudes than are shown by the DWBA calculations. The WBP prediction also follows the trend of the data fairly well, but the maxima and

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[27] L. S. Rodberg, Nucl. Phys. **15**, 72 (1959); L. C. Biedenharn and G. R. Satchler, Helv. Phys. Acta Suppl. **V1** (1960).

[28] D. W. Miller, in *Proceedings of the International Symposium on Polarization Phenomena of Nucleons, Karlsruhe, 1965*, edited by P. Huber and H. Schopper (W. Rosch and Co., Bern, 1966).

[29] P. Schwandt and W. Haeberli, Nucl. Phys. **A123**, 401 (1969).

[30] P. Schwandt (private communication).

[31] L. Rosen, J. G. Beery, A. S. Goldhaber, and E. H. Auerbach, Ann. Phys. (N.Y.) **34**, 96 (1965).

[32] G. W. Greenlees and G. J. Pyle, Phys. Rev. **149**, 836 (1966).

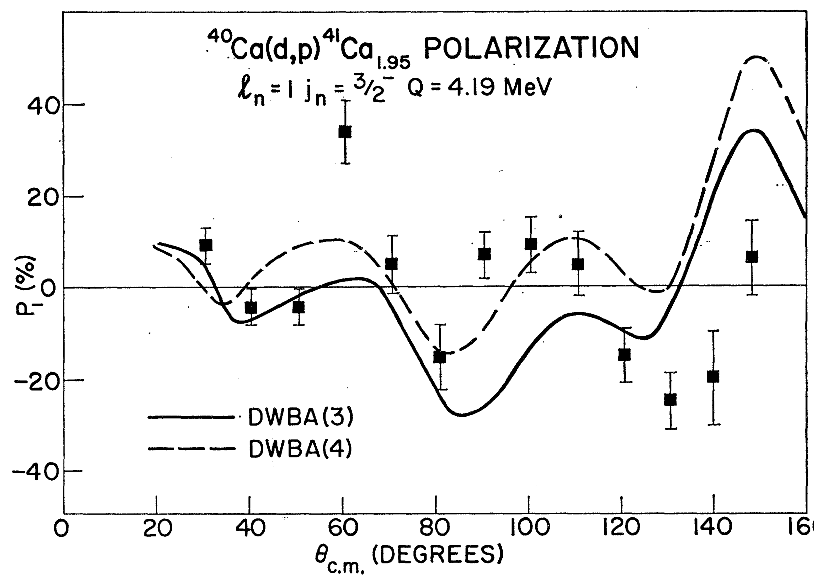

FIG. 7. Present results for the polarizations of protons produced in the reaction ^{40}Ca(d, p)^{41}Ca leading to the 1.95-MeV state of ^{41}Ca (indicated by the black squares) compared with specific DWBA results by Schwandt and Haeberli (Refs. 29 and 30) discussed in the text.

minima are displaced to somewhat larger angles than observed experimentally. The BHMM curve using Rosen parameters shown in Fig. 6 does not indicate another minimum at back angles. However, May and Truelove also plot BHMM predictions for E_d = 12 MeV using the neutron optical potential of Perey and Buck[33] which are very similar to the BHMM curve in Fig. 6 but show a slight dip around 165°. These predictions still do not match well with the present experimental results, which indicate much sharper minima and a back-angle dip around 140°.

Figure 7 compares the experimental data for the polarization of protons from the reaction ^{40}Ca(d, p)^{41}Ca exciting the 1.95-MeV state with two DWBA calculations by Schwandt and Haeberli.[29,30] The parameters employed in the curves labeled DWBA (3) and (4) were the same as those employed in curves DWBA (1) and (2), respectively, in Fig. 6. Here also the periodicity of the data is matched by that of the theoretical curves, but the magnitude of the proton polarization is not reproduced in the backward direction.

Only one published prediction for the reaction ^{40}Ca(d, p)^{41}Ca leading to the 2.47-MeV state is available at present. This prediction is by Delic and Robson[34] and examines the effect of tensor forces in the deuteron-nucleus interaction. However, the prediction has little resemblance to Fig. 4, and is not reproduced here.

V. CONCLUSIONS

Measurements of the polarizations of protons emitted in the reactions ^{40}Ca(d, p)^{41}Ca corresponding to the ground, 1.95- and 2.47-MeV states of ^{41}Ca at a deuteron energy of 10.8 MeV over the laboratory angular range from 30° to 148° show good agreement with previous experiments performed at similar energies whenever the angles studied overlap. There is a possible suggestion of an anomalous behavior for the polarization of protons from the reaction ^{40}Ca(d, p)^{41}Ca leading to the 2.47-MeV state in the same angular region where the differential cross section for the reaction ^{40}Ca(d, p)^{41}Ca leading to the 3.95-MeV state exhibits a deep minimum. Comparison of the present polarization data with theoretical predictions of the DWBA, BHMM, and WBP models shows only fair agreement.

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