Polarization of Protons from Deuteron Stripping Reactions with $l=1$ Orbital Angular Momentum Transfer*

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The angular dependence of the polarization of protons from (d,p) reactions with 15-MeV deuteron energy has been measured for several transitions associated with $l=1$ neutron capture; $C^{12}(d,p)C^{13}{}_{g.s.}$, $Mg^{24}(d,p)Mg^{25}{}_{3.40\text{ MeV}}$, $Ca^{40}(d,p)Ca^{41}{}_{1.95\text{ MeV}}$, $Ca^{40}(d,p)Ca^{41}{}_{2.469\text{ MeV}}$, and $V^{51}(d,p)V^{52}{}_{g.s.}$. The polarization patterns reveal some features characteristic of distortion polarization in the main stripping peak region; however, spin-orbit polarization seems to be predominant and to determine the general features of the angular dependence of the polarization.

I. INTRODUCTION

THE polarization of protons from (d,p) reactions at 15 MeV has been measured in several cases as a function of the angle. Results for transitions corresponding to a zero angular momentum transfer have been published in the associated paper[1] in this issue. Results of a series of measurements of the polarization in $l=1$ transitions are reported in the present paper.

Recent elaborate calculations of the stripping process in the distorted wave Born approximation give a quite accurate description of the (d,p) reactions.[2] Agreement with the experiment is observed not only in the shape of the angular distribution, but also in the absolute value of the cross section. It can then be expected that a calculation in the same approximation will also reproduce the value of the proton polarization. Comparison of the calculated polarization angular dependence with the experimental curve is a quite sensitive test for judging how accurately the distortion of the incoming and outgoing waves is represented by the optical potential used in the calculations.

Any interaction in the incident and outgoing channels causes polarization of the outgoing protons.[3] If the spin-dependent term in the potential is neglected, the polarization is expressed by the following formula[4]:

$$P=\frac{1}{3}\left[\frac{\theta_{l,l+\frac{1}{2}}{}^2}{l+1}-\frac{\theta_{l,l-\frac{1}{2}}{}^2}{l}\right]\frac{1}{\theta_{l,l+\frac{1}{2}}{}^2+\theta_{l,l-\frac{1}{2}}{}^2}\frac{\sum_m m|B_{l,m}|^2}{\sum_m|B_{l,m}|^2},\qquad(1)$$

where only one transfer angular momentum l is considered, m is the component of $\mathbf{l}$ along the quantization axis defined by $\mathbf{k}_d\times\mathbf{k}_p$, $B_{l,m}$ is the matrix element for capture of the neutron in an orbit with quantum numbers l, m and includes every detail of the distortion, and $\theta_{l,j}{}^2$ is the reduced width of the final state. The sign of the polarization is taken positive when the polarization vector is directed as $\mathbf{k}_d\times\mathbf{k}_p$. Formula (1), assuming that only one j value is involved in the transition, puts the following upper limits in the proton polarization for the $l=1$ cases:

$$|P|\leq\tfrac{1}{3}\quad\text{for}\quad j=\tfrac{1}{2},\quad l=1$$
$$|P|\leq\tfrac{1}{6}\quad\text{for}\quad j=\tfrac{3}{2},\quad l=1.$$

If the effect of the absorptive distortion is predominant, the sign can be predicted by a semiclassical argument, first given by Newns[3]; if deuteron absorption is stronger than proton absorption the neutron capture contributing the outgoing proton flux occurs, preferably, in the half of the sphere representing the nucleus closer to the incident deuteron. In this part of the nucleus, the neutron is captured in average with a positive m value for geometrical reasons. Therefore, the last factor in formula (1), which expresses a mean value of m, is always positive. Then, we obtain a rule that P is positive if $j=l+\frac{1}{2}$ and negative if $j=l-\frac{1}{2}$. This rule seems to be fulfilled in several of the cases so far observed,[5] but a few cases which contradict this rule have also been found.[6] In the main stripping peak region, where the description of the process with the semiclassical picture should be appropriate, the effect of the absorption on the polarization sign is expected to be predominant.

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[5] J. C. Hensel and W. C. Parkinson, Phys. Rev. **110**, 128 (1958); A. C. Juveland and W. Jentschke, *ibid.* **110**, 456 (1958); R. G. Allas and F. B. Shull, *ibid.* **116**, 996 (1959), and Bull. Am. Phys. Soc. **6**, 24 (1961). A summary of experimental data is found in L. J. B. Goldfarb, *Proceedings of the Rutherford Jubilee International Conference, Manchester, 1961* (Academic Press Inc., New York, 1961).

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II. EXPERIMENTAL

Fifteen-MeV deuterons from the University of Pittsburgh cyclotron were energy-analyzed and focused on the targets. The protons from the (d,p) reaction were analyzed by a 60° sector focusing magnet, and subsequently their polarization was measured by means of a second scattering on a carbon target. The resolution in the proton spectra was of the order of 200 keV, so that in all the cases studied the desired proton group is well separated from the other proton groups. Details of the triple coincidence counter arrangement used in the carbon polarimeter, of the method of alignment of the polarimeter axis, and a discussion of the possible sources of errors have been given in a previous paper.[1]

The energies of the protons from the transitions studied in this work range from 13.5 to 19.5 MeV. In this energy region the magnitude of the polarization of the carbon analyzer is considerably large. For protons of energy higher than about 17 MeV a scatterer of the thickness of 129 mg cm^{-2} is used, while for lower energy protons 72 mg cm^{-2} is utilized. In order to find the effective polarization value $P_2^{\text{eff}}(E)$ of the carbon analyzer, it is necessary to take an average over the scattering angles and the energy range of the incident protons. The average value of carbon polarization P_2^{av} for elastic scattering, weighted with the differential cross section, is shown in Fig. 1 (curves *a* and *b*). As was mentioned in the previous paper[1] a considerable fraction of the inelastic protons (corresponding to the excitation of the 4.43-MeV level of C^{12}) is counted by the detectors together with the elastic protons. Thus, $P_2^{\text{eff}}(E)$ should include the contribution from this inelastic proton group:

$$P_2^{\text{eff}}(E)=\frac{\eta\sigma_{\text{av}}P_2^{\text{av}}+\eta'\sigma_{\text{av}}'P_2'^{\text{av}}}{\eta\sigma_{\text{av}}+\eta'\sigma_{\text{av}}'},$$

where P_2^{av} and $P_2'^{\text{av}}$ are the average polarization for elastic and inelastic protons, respectively, σ_{av} and σ_{av}' are the respective average cross sections, and η and η' are the geometrical means of the counting efficiencies of the right and left counters, respectively. $P_2^{\text{eff}}(E)$ defined in this way gives, to a good approximation, the usual relation between the incident beam polarization P_1 and the right-left asymmetry A, $A=P_1P_2^{\text{eff}}(E)$. Here it is assumed that the relation between the polarization and the right-left asymmetry in elastic scattering is valid also for the inelastic scattering. It has been argued by Squires[7] that this assumption is approximately correct (polarization-asymmetry equality).

Polarization of the inelastic protons from the 4.43-MeV level in C^{12} has been measured only at 17.7 MeV by Brockman.[8] The pattern of the angular dependence of the polarization is found to be similar to that for elastic scattering, in agreement with a suggestion by Levinson, reported in the same paper, that the effect of the spin-orbit interaction should be analogous in the two cases. Thus, in general, it may be assumed that $P_2'^{\text{av}}$ is not very much different from P_2^{av} in formula (3). Since the ratio $\eta'\sigma_{\text{av}}'/\eta\sigma_{\text{av}}$ in our experimental conditions, is 1/5 to 1/6, the effect of the inelastic group on the $P_2^{\text{eff}}(E)$ value should be moderately small.

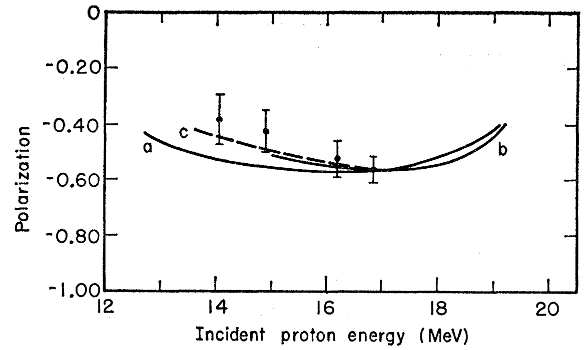

FIG. 1. Effective polarization of the carbon analyzer. Curves (*a*) and (*b*) give the values calculated for 72-mg cm^{-2} and 129-mg cm^{-2} carbon targets, respectively. The experimental points give the values for the 72-mg cm^{-2} target obtained in the calibration with proportional counter telescopes. Curve (*c*) gives the intermediate values used in the scintillation counter measurements.

An attempt has been made to measure experimentally the extent of the effect of the inelastic protons on the energy dependence of $P_2^{\text{eff}}(E)$. In our experimental apparatus, the counting efficiency for inelastic protons is highest when the proportional counters are used.[1] A calibration curve was taken using these counters and degrading the energy of protons from the same reaction at the same angle. A highly polarized proton beam from the reaction $C^{12}(d,p)C^{13}{}_{\text{g.s.}}$ was used. The result is compared in Fig. 1 with the curve (*a*) of P_2^{av} obtained from averaging the elastic scattering data. Measured values for $P_2^{\text{eff}}(E)$ are normalized to coincide with the elastic value P_2^{av} at 16.8 MeV; at this energy the measurement was repeated using the CsI counters and the same right-left asymmetry was obtained as with the proportional counters. The pulse-height selector bias for the CsI counter was set high enough to eliminate most of the inelastic protons; then we can deduce that at 16.8 MeV there is no large difference between P_2^{av} and P_2^{eff}. In the energy region lower than 15 MeV, the measured values of P_2^{eff} are fairly smaller than P_2^{av}. This corresponds to nearly zero polarization in the inelastic scattering. It is not clear whether this reduction is due to the effect of the inelastic proton group or if it is to be ascribed to a possible experimental error due to the large reduction of the incident proton energy by the absorber. However, we do not need very accurate values of P_2^{eff} in this energy region, because it corresponds to proton energies obtained only at the largest angles in the $C^{12}(d,p)C^{13}{}_{\text{g.s.}}$, where the measurement was taken only with a large statistical error.

[7] E. J. Squires, Nuclear Phys. **6**, 509 (1958).
[8] K. W. Brockman, Phys. Rev. **110**, 163 (1958).

III. RESULTS

Measurements have been taken of the angular dependence of the polarization for five $l=1$ transitions;

$$C^{12}(d,p)C^{13}{}_{g.s.},\quad Mg^{24}(d,p)Mg^{25}{}_{3.40\,\mathrm{MeV}},$$
$$Ca^{40}(d,p)Ca^{41}{}_{1.95\,\mathrm{MeV\ and\ 2.469\ MeV}},\ \text{and}\ V^{51}(d,p)V^{52}{}_{g.s.}.$$

The measured right-left asymmetries, the P_2^{eff} in the relevant conditions, and the proton polarization P_1 are listed in Tables I to V. The angular dependence of the polarization are shown in Figs. 2 to 6 together with the corresponding angular distributions of the cross sections.[9–11] The errors indicated are due to counting statistics only. The errors due to an instrumental asymmetry cannot give rise to an apparent asymmetry larger than ± 0.02. The errors due to the uncertainty in the analyzer polarization are at most 10% of the measured values.

TABLE I. Polarization of protons from the reaction $C^{12}(d,p)C^{13}{}_{g.s.}$.

θ_{lab} (deg)	$\theta_{c.m.}$ (deg)	E_p (MeV)	$P_1P_2^{\mathrm{eff}}$	P_2^{eff}	P_1
10.0	11.0	16.85	+0.173±0.026	−0.56	−0.309±0.046
15.0	16.6	16.85	+0.113±0.020	−0.56	−0.202±0.036
20.0	22.1	16.65	+0.085±0.016	−0.55	−0.155±0.029
30.0	33.0	16.45	+0.038±0.021	−0.55	−0.069±0.038
35.0	38.5	16.30	+0.042±0.046	−0.54	−0.078±0.085
40.0	43.9	16.10	+0.216±0.031	−0.53	−0.408±0.058
45.0	49.3	15.85	+0.110±0.039	−0.52	−0.221±0.075
50.0	54.6	15.65	+0.171±0.040	−0.52	−0.329±0.077
60.0	65.2	15.25	+0.172±0.044	−0.50	−0.344±0.088
70.0	75.7	14.70	+0.061±0.037	−0.48	−0.127±0.077
80.0	86.0	13.65	−0.214±0.062	−0.43	+0.498±0.144

TABLE II. Polarization of protons from the reaction $Mg^{24}(d,p)Mg^{25}{}_{3.40\,\mathrm{Mev}}$.

θ_{lab} (deg)	$\theta_{c.m.}$ (deg)	E_p (MeV)	$P_1P_2^{\mathrm{eff}}$	P_2^{eff}	P_1
10.0	10.6	15.65	+0.023±0.021	−0.49	−0.047±0.042
15.0	15.8	15.60	−0.002±0.016	−0.49	+0.003±0.032
22.0	23.2	15.50	−0.031±0.026	−0.48	+0.065±0.052
30.0	31.6	15.45	+0.136±0.048	−0.48	−0.283±0.100
37.0	38.9	15.45	+0.037±0.049	−0.48	−0.077±0.100

TABLE III. Polarization of protons from the reaction $Ca^{40}(d,p)Ca^{41}{}_{1.950\,\mathrm{Mev}}$.

θ_{lab} (deg)	$\theta_{c.m.}$ (deg)	E_p (MeV)	$P_1P_2^{\mathrm{eff}}$	P_2^{eff}	P_1
10.0	10.3	18.25	−0.023±0.023	−0.525	+0.044±0.044
15.0	15.4	18.25	−0.032±0.020	−0.525	+0.060±0.040
20.0	20.6	18.20	+0.022±0.026	−0.53	−0.042±0.048
22.5	23.1	18.20	+0.024±0.032	−0.53	−0.046±0.060
25.0	25.7	18.15	−0.002±0.030	−0.53	+0.004±0.057
30.0	30.9	18.10	−0.051±0.040	−0.53	+0.095±0.075

[9] E. W. Hamburger, Phys. Rev. **123**, 619 (1961).
[10] T. P. Martin, K. S. Quisenberry, and C. A. Low, Jr., Phys. Rev. **20**, 442 (1960).
[11] J. R. Holt and T. N. Marsham, Proc. Phys. Soc. (London) **A66**, 467 (1953).

IV. DISCUSSIONS OF THE INDIVIDUAL CASES

In all the cases studied the $l=1$ character of the transition has been established from the angular distribution measurement. Owing to their large reduced width[12] it may be assumed that rather pure single-particle states of the final nucleus are involved in the neutron capture.

$C^{12}(d,p)C^{13}{}_{g.s.}$ ($l=1, j=1/2$)

This reaction has been most widely studied as long as polarization in a stripping reaction is concerned. A compilation of the available data, including the present data, is given by Gondfarb.[5] The angular dependence and magnitude of the polarization are fairly constant

TABLE IV. Polarization of protons from the reaction $Ca^{40}(d,p)Ca^{41}{}_{2.469\,\mathrm{Mev}}$.

θ_{lab} (deg)	$\theta_{c.m.}$ (deg)	E_p (MeV)	$P_1P_2^{\mathrm{eff}}$	P_2^{eff}	P_1
10.0	10.3	17.80	−0.012±0.040	−0.55	+0.022±0.073
15.0	15.4	17.70	−0.030±0.030	−0.55	+0.054±0.055
20.0	20.6	17.65	+0.076±0.040	−0.55	−0.139±0.072
22.5	23.1	17.60	−0.012±0.040	−0.55	+0.021±0.070
25.0	25.7	17.60	−0.030±0.050	−0.55	+0.055±0.090
30.0	30.9	17.50	−0.011±0.060	−0.55	+0.019±0.108

TABLE V. Polarization of protons from the reaction $V^{51}(d,p)V^{52}{}_{g.s.}$.

θ_{lab} (deg)	$\theta_{c.m.}$ (deg)	E_p (MeV)	$P_1P_2^{\mathrm{eff}}$	P_2^{eff}	P_1
10.0	10.1	19.05	+0.020 ±0.030	−0.43	−0.046±0.070
15.0	15.2	19.05	+0.003 ±0.022	−0.43	−0.007±0.050
20.0	20.3	18.95	−0.022 ±0.026	−0.435	+0.049±0.060
25.0	25.4	18.95	−0.0152±0.034	−0.445	+0.026±0.076
30.0	30.5	18.95	−0.031 ±0.051	−0.455	+0.068±0.110
40.0	40.7	18.95	+0.085 ±0.040	−0.445	−0.191±0.090
45.0	45.8	18.95	+0.098 ±0.060	−0.445	−0.221±0.135
50.0	50.9	18.90	+0.140 ±0.070	−0.455	−0.308±0.154

in the energy range from 7 to 15 MeV and the sign of polarization is negative at forward angles in accordance with the prediction of the distorted wave theory. The constancy of the angular dependence of the polarization is probably correlated to the fact that the differential cross section has approximately a constant shape in the same energy region, although the cross section increases at lower energies.[9]

$Mg^{24}(d,p)Mg^{25}{}_{3.40\,\mathrm{Mev}}$ ($l=1, j=3/2$)

The j value was determined by $(\gamma-\gamma)$ angular correlation measurements.[13] A (d,p,γ) angular correlation experiment[10] has been done in this laboratory at 15° and 45° for the same deuteron energy as used in

[12] M. H. Macfarlane and J. B. French, Revs. Modern Phys. **32**, 567 (1960).
[13] G. Manning and G. A. Bartholomew, Phys. Rev. **115**, 40 (1959).

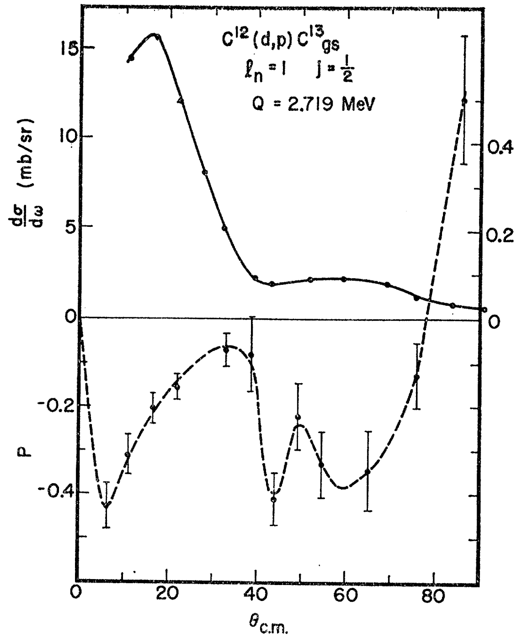

FIG. 2. Polarization of protons from the reaction $C^{12}(d,p)C^{13}{}_{g.s.}$. The angular distribution of the cross section, taken from reference 9, is also plotted.

the present work. It is interesting to compare both experiments because the distorted wave Born approximation theory[4] gives the following relation between the two measurements:

$$P=-\frac{3}{2}\frac{(1-\lambda)^{\frac{1}{2}}}{2j+1},\quad \lambda=\frac{2}{|B_{1,-1}/B_{1,+1}|+|B_{1,+1}/B_{1,-1}|},$$

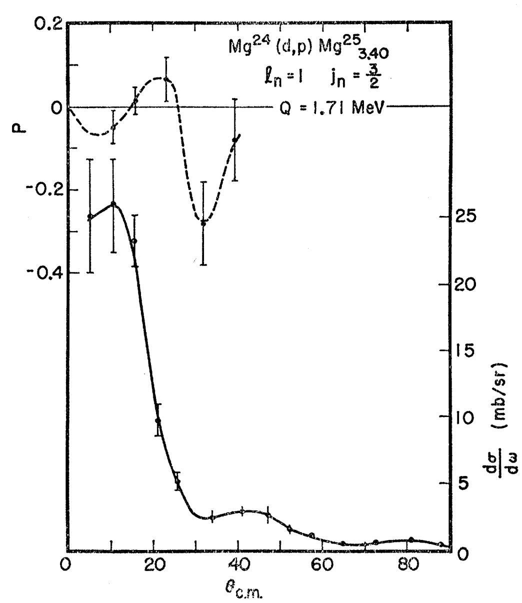

FIG. 3. Polarization of protons from the reaction $Mg^{24}(d,p)$-$Mg^{25}{}_{3.40\ \mathrm{MeV}}$. The angular distribution of the cross section, taken from reference 10, is also plotted.

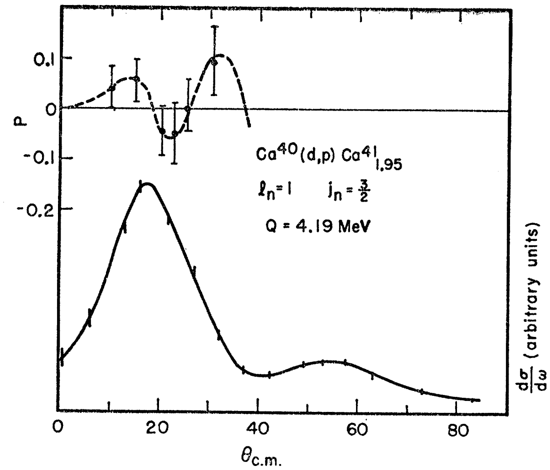

FIG. 4. Polarization of protons from the reaction $Ca^{40}(d,p)$-$Ca^{41}{}_{1.95\ \mathrm{MeV}}$. The angular distribution of the cross section which is also plotted is taken from a measurement at 8-MeV incident deuteron energy (reference 11).

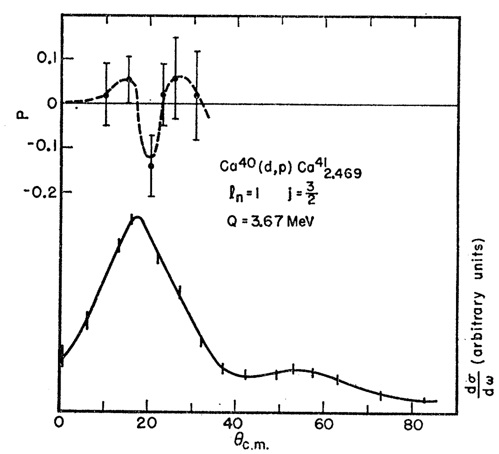

FIG. 5. Polarization of protons from the reaction $Ca^{40}(d,p)$-$Ca^{41}{}_{2.964\ \mathrm{MeV}}$. The angular distribution of the cross section which is also plotted is taken from a measurement at 8-MeV incident deuteron energy (reference 11).

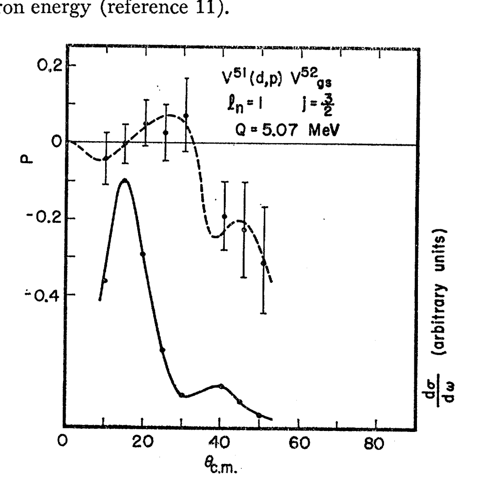

FIG. 6. Polarization of protons from the reaction $V^{51}(d,p)V^{52}{}_{g.s.}$. The angular distribution of the cross section which is also plotted was obtained in the present measurement.

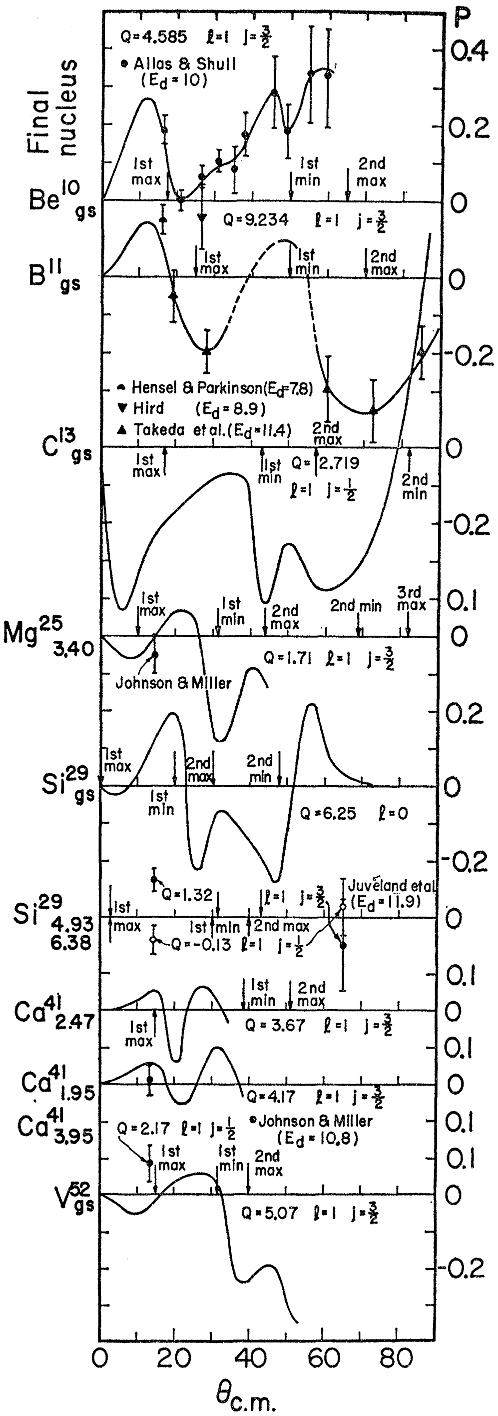

FIG. 7. Plots of the polarization angular dependence curves obtained so far in other laboratories and in the present experiments. For the latter data, only the curves are shown for simplicity. Arrows on the zero lines indicate the angles at which occur the maxima and minima of the corresponding differential cross sections.

where $B_{1,+1}$ and $B_{1,-1}$ are the transition matrix elements B_{1m} for $l=1$ and $m=+1$ and -1, respectively. Inserting the values of λ obtained in the (d,p,γ) experiment, the absolute magnitudes of the polarization are found to be $|P_{(15°)}|=0.096\pm0.026$ and $|P_{(45°)}|=0.101\pm0.019$. This value is not in good agreement with the present result ($P_{(15°)}=0.003\pm0.032$). The discrepancy is probably to be ascribed to the neglect of spin-dependent forces in the above theory.

$Ca^{40}(d,p)Ca^{41}{}_{1.947\text{ MeV}}$ $(l=1, j=3/2)$ and $Ca^{40}(d,p)Ca^{41}{}_{2.469\text{ MeV}}$ $(l=1, j=3/2)$

The j value of the transition to the 1.947-MeV level has been determined to be 3/2 from the measurement of the circular polarization of γ rays emitted after capture of a polarized neutron.[14] Since the angular dependence and the magnitude of the polarization of the proton group from the 2.469-MeV level are almost the same as those of the protons from the 1.947-MeV level, the j value for the former level is also very probably 3/2. This assignment is confirmed by sum rule considerations for the reduced widths.[12] There is a small amount of shift in the relative positions of the two curves. The direction of the shift agrees with that expected from the plane-wave stripping theory because of the difference in the Q values (increasing the Q-value shifts the angular distribution pattern to larger angles).

$V^{51}(d,p)V^{52}{}_{\text{g.s.}}$ $(l=1, j=3/2)$

The assignment of $2p_{3/2}$ to the shell-model state into which the neutron is captured in this transition has been done by Schiffer and Lee.[15] The same assignment is also accepted by Dalton.[16]

V. GENERAL FEATURES OF THE POLARIZATION ANGULAR DEPENDENCE

In Fig. 7, the polarization angular dependence curves are arranged in order of target mass number, the angles at which the maxima and minima of the differential cross sections occur are also indicated. The curves for the $l=0$ transitions, presented in the previous paper,[1] and those for the $l=1$ transitions $Be^9(d,p)Be^{10}{}_{\text{g.s.}}$, taken from Allas and Shull,[5] and $B^{10}(d,p)B^{11}{}_{\text{g.s.}}$ from Hensel and Parkinson,[5] Hird *et al.*, and Takeda *et al.*[6] are plotted. The values of the polarization at about 13° for the transitions $Mg^{24}(d,p)Mg^{25}{}_{3.40\text{ MeV}}$ and $Ca^{40}(d,p)Ca^{41}{}_{1.95\text{ MeV}}$ given by Johnson and Miller[17] and those at 14.5° and 65° for the transition $Si^{28}(d,p)Si^{29}$ given by Juveland and Jentschke[5] are also indicated.

In the latter cases the deuteron energies are somewhat lower than in the present experiments, but no large change in the yield and polarization patterns is expected at different energies, as observed in the case of carbon. General features of the curves in Fig. 7 may be summarized in the following way.

[14] G. Trumpy, Nuclear Phys. 2, 664 (1956/57).
[15] J. P. Schiffer and L. L. Lee, Phys. Rev. 115, 427 (1959).
[16] A. W. Dalton, Proc. Phys. Soc. (London) 75, 95 (1960).
[17] W. P. Johnson and D. W. Miller, *Proceedings of the Rutherford Jubilee International Conference, Manchester, 1961* (Academic Press Inc., New York, 1961), paper C5/36.

(1) The patterns for Mg and V, which are associated to capture into $2p_{3/2}$ shell states, present a marked similarity; polarization is slightly negative at forward angles and positive on the right side of the stripping peak. Near the first minimum it swings to a large negative value (20~30%). The stripping peak for V is shifted a little towards larger angles relative to that for Mg probably because of the effect of the Coulomb force. At large angles in the case of V the yield changes more rapidly with angle than in the case of Mg as expected from the plane-wave stripping theory due to the difference in Q values and in nuclear radii. A corresponding shift of the pattern is also found in the polarization angular dependence.

(2) The patterns for the transitions to the two $2p_{3/2}$ shell levels in Ca^{41} are very similar to each other. They have a more complex structure in the angular region before the first minimum compared to the patterns for Mg and V. Although for these transitions our measurements are not extended to larger angles, a swing to negative values can be expected to occur near the first minimum as observed in the other cases.

(3) The occurrence of a large swing to negative values near the first stripping minimum and a negative polarization in the second stripping peak region have been observed quite definitely for the $l=0$ transitions (Al and Si) in the previous paper.[1] This feature seems to be present also in most of the $l=1$ transitions. In the case of C^{13}, the curve swings very clearly, although the sign of the polarization does not change. The data for the transition to the $1p_{3/2}$ shell level in B^{11}, which are too coarse to reveal fine structure and show some discrepancies between the values obtained by different authors, may be fitted by a curve as the one shown in Fig. 7, in agreement with the general trend. The only data in contradiction with this trend are those for the transition to the ground state of Be^{10}.

(4) The pattern for the $l=1$ transitions in the angular region before the first minimum reflects the difference in j value. The proton polarization for the transition to the ground states of C^{13} and Be^{10} is, respectively, negative and positive through this region in conformity with the sign rule of the distortion polarization which has been mentioned in the introduction. For the other cases (all of which are $j=3/2$ cases), this feature of distortion polarization does not reveal itself explicitly. The sign rule is always fulfilled only on the right side of the main stripping peak. This explains why the polarization sign, so far observed, is in agreement with the sign rule in some cases and in disagreement in others.

(5) If the zero-polarization line in the angular dependence curve for the transition to the ground state of C^{13} in Fig. 7 is lowered in such a way as to subtract a part of the negative polarization, one finds that the resulting pattern is very similar to the patterns for Al^{28} and Si^{29} or to those for the $p_{3/2}$ levels (Mg^{25}, Ca^{41}, V^{52}, and B^{11}). Since the pattern for $l=0$ transitions is given by spin-orbit polarization only, we can say that the part of negative polarization which has been subtracted in this way seems to represent the distortion polarization for the transition to the ground state of C^{13}. Such an additive nature of both types of polarization can be shown by the simple perturbation treatment which considers the effects of distortion (or absorption) and spin-orbit interactions as small perturbations to the main stripping amplitude; the polarization occurs mainly as an interference between the main stripping amplitude and the perturbation amplitudes, so that the polarizations due to two different effects are additive. The distortion polarization for $2p$-shell levels seems to be smaller than that for $1p$-shell levels (Be^{10}, B^{11}, C^{13}), the polarization for the former group consisting mostly of spin-orbit polarization.

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