States of ^{25}Mg Excited by 180° Electron Scattering

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Several states in ^{25}Mg have been excited by 180° inelastic electron scattering at bombarding energies of 39 and 56 MeV. A survey was made of the giant-resonance region comprising the upper half of the excitation range 0–27 MeV. In the lower half of this range, studied more intensively, the scattering has caused magnetic dipole transitions to states at 1.60, 5.77, 7.03, 7.81, 10.43, 11.37, and 11.76 MeV. Transition radii and ground-state transition widths are given for these levels. The results are discussed with respect to the collective rotational nature of the nucleus and to the existence of $T=\frac{3}{2}$ analog states.

I. INTRODUCTION

Nuclear reactions and Coulomb excitation have proved to be extremely useful techniques in studies of the collective rotational properties of distorted nuclei. As a result of such studies, the rotational nature of the ^{25}Mg nucleus has been known for some time.[1–4] Nevertheless, such a nucleus has not yet been extensively studied by electron scattering in a way that highlights its rotational characteristics. The work presented here constitutes a rather clear-cut example of such a study. A portion of our discussion is devoted to demonstrating this.

We also discuss the excitation of $T=\frac{3}{2}$ analogs of states in ^{25}Na and the relation of the results to the work of Morrison *et al.*[5] on the lowest two of these states. Energies, transition radii, and ground-state transition widths upon which these discussions are based are given for the excitation region 0–12 MeV. Beyond this excitation energy up to 27 MeV, only a "survey" spectrum at the 56-MeV bombardment was obtained in order to determine qualitatively the shape in the giant-resonance region.

II. THEORETICAL AND EXPERIMENTAL CONSIDERATIONS

The experimental results of this paper are compared with model-independent theoretical expressions[6] based on the Born approximation [subject to a distorted-wave Born approximation (DWBA) correction (see Sec. III)]. Since magnetic transitions are generally dominant at 180°, we use the magnetic scattering differential cross section [Ref. 6, Eq. (5)]:

$$\left(\frac{d\sigma}{d\Omega}\right)_{180°}=\frac{\pi\alpha}{[(2L+1)!!]^2}\frac{L+1}{L}\frac{q^{2L}}{k_1^2}B(ML,q), \quad (1)$$

where L is the multipolarity, q is the momentum transfer, k_1 is the incident electron momentum, and B is the reduced transition probability. The latter is expanded in terms of q and the transition radii [Ref. 6, Eq. (13a)]:

$$B(ML,q)=B(ML,0)\left(1-\frac{L+3}{L+1}\frac{(qR_M)^2}{2(2L+3)}+\frac{L+5}{L+1}\frac{(qR_M{}^*)^4}{8(2L+3)(2L+5)}+\cdots\right)^2, \quad (2)$$

where R_M and $R_M{}^*$ are transition radii as defined in Ref. 6.

Setting $R_M{}^*=R_M$, one may use the above expressions in conjunction with the experimentally measured cross sections to determine R_M, L, and $B(ML,0)$ as described in Ref. 7. The ground-state radiation width can then be determined from [Ref. 6, Eq. (15a)]

$$\Gamma_0=\frac{8\pi}{[(2L+1)!!]^2}\frac{L+1}{L}\frac{2J_0+1}{2J+1}\omega^{2L+1}B(ML,\omega), \quad (3)$$

where ω is the excitation energy and J_0 and J are the ground- and excited-state spins,[8] respectively.

Considerable doubt has recently been expressed by Drechsel[9] as to whether R_M has any model-independent physical meaning as a transition radius. In our work thus far[7,10,11] it has not been our intention to give it physical meaning. However, one might infer that we did to the extent that in our analysis[7] we require the correct value of L to yield a transition radius roughly

[1] H. E. Gove, G. A. Bartholomew, E. B. Paul, and A. E. Litherland, Nucl. Phys. **2**, 132 (1956).
[2] S. Hinds, H. Marchant, and R. Middleton, Proc. Phys. Soc. (London) **78**, 473 (1961).
[3] R. K. Sheline and R. A. Harlan, Nucl. Phys. **29**, 177 (1962).
[4] G. J. McCallum and B. D. Sowerby, Phys. Letters **25B**, 109 (1967).
[5] G. C. Morrison. D. H. Youngblood, R. C. Bearse, and R. E. Segel, Phys. Rev. **174**, 1366 (1968). In specifying states in this work and in ours we use the notation (T,J^π,K^π).
[6] M. Rosen, R. Raphael, and H. Überall, Phys. Rev. **163**, 927 (1967).
[7] L. W. Fagg, W. L. Bendel, R. A. Tobin, and H. F. Kaiser, Phys. Rev. **171**, 1250 (1968).
[8] The ratio involving the nuclear spins in this expression was erroneously squared in Ref. 7. Also, the sign for the summation over L has been omitted here and in Eq. (1), since in this work only one value of L has significantly contributed.
[9] D. Drechsel, Nucl. Phys. **A113**, 665 (1968).
[10] W. L. Bendel, L. W. Fagg, R. A. Tobin, and H. F. Kaiser, Phys. Rev. **173**, 1103 (1968).
[11] L. W. Fagg, W. L. Bendel, E. C. Jones, Jr., and S. Numrich, Phys. Rev. **187**, (1969).

equal to the nuclear-matter radius. It happens that this criterion has yielded consistency in the results. In any event, even if we relegate R_M to being a convenient parameter, and use the criterion that the transition radii for all transitions of the same multipolarity must be roughly equal, our experimental results would still be the same. Thus it should not be inferred that our results indicate anything definite concerning the physical significance of R_M.

It should also be pointed out that our analysis cannot exclude the possibility of transverse electric dipole excitation occurring. However, to the best of our knowledge, only a few such cases have been reported.[12]

In this experiment, a 73.3-mg/cm^2-thick ^{25}Mg target, isotopically enriched to 91.54%, was bombarded with 39- and 56-MeV electrons from the NRL 60-MeV Linac. The 180° scattering apparatus including the magnetic spectrometer, associated detector system, and the beam measuring system has been described in detail in Ref. 10. The methods of energy calibration[10] and of the treatment of the data[7] are also given in earlier reports.

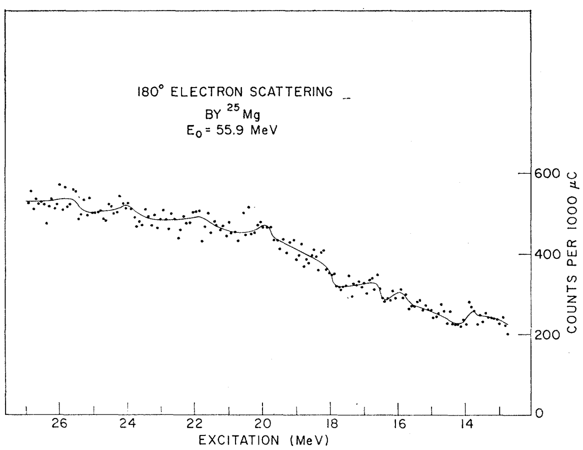

FIG. 1. Spectrum obtained from 180° electron scattering by ^{25}Mg with $E_0=55.9$ MeV, covering the excitation energy range 12–27 MeV.

III. RESULTS

Since no significant peaks in the spectra were observed above an excitation energy of 12 MeV, all of the quantitative analysis was conducted below this energy. However, a survey was made at 56-MeV electron bombardment and 1000-μC accumulation to search for any prominent magnetic transitions in the 12–27-MeV region. Although none were found, the results of this survey are presented in Fig. 1 to give a qualitative picture of the spectrum shape in the giant-resonance region.

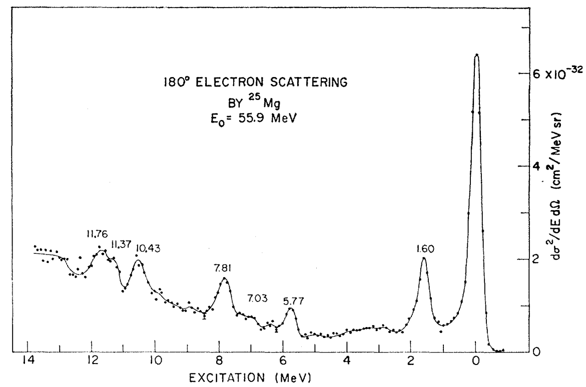

FIG. 2. Differential cross section for 180° electron scattering from ^{25}Mg with $E_0=55.9$ MeV, covering the excitation energy range 0–12 MeV.

Quantitative results for transitions of less than 12 MeV were obtained from the two spectra at 55.9 and 38.9 MeV. These spectra, in terms of the differential cross section and based on 3000- and 2000-μC accumulations, are presented in Figs. 2 and 3, respectively. The contributions resulting from an 8.29% content of ^{24}Mg in the target were not subtracted from the spectra, but were in the data analysis. Because the strong peaks in the ^{24}Mg spectra[7] are at 9.9 and 10.7 MeV, only the ^{25}Mg structure at these energies was significantly affected.

The energy, inelastic cross sections, isospin, spin and parity, spin projection on the nuclear axis, transition radius, and ground-state radiation width of each of the levels excited are presented in Table I. The peak areas upon which these results are based were subjected to the usual Schwinger, bremsstrahlung, and ionization corrections. The uncertainties given for the cross sections are relative values based on uncertainties in

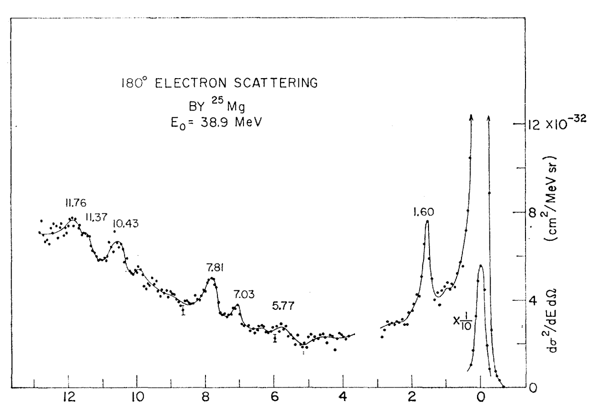

FIG. 3. Differential cross section for 180° electron scattering from ^{25}Mg with $E_0=38.9$ MeV, covering the excitation energy range 0–12 MeV. The gap in the spectrum arises from the fact that a preliminary survey, as well as the 56-MeV data, showed no structure of interest in this region; thus presentable data were not accumulated here.

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[12] G. Clerc (private communication); see also Y. Torizuka, M. Oyamada, K. Nakahara, K. Sugiyama, K. Kojima, T. Terasawa, K. Itoh, A. Yamaguchi, and M. Kimura, Phys. Rev. Letters **22**, 544 (1969).

TABLE I. Values of differential cross section, isospin, spin and parity, spin projection on the nuclear axis, transition radius, and radiation width for energy levels excited in ^{25}Mg.

Level energy (MeV)	$(d\sigma/d\Omega)_{56}$ (10^{-34} cm^2/sr)	$(d\sigma/d\Omega)_{39}$	T	J^π	K^π	Plane-wave Born approximation R_M (fm)	$\frac{2J+1}{2J_0+1}\Gamma_0$ (eV)	DWBA corrections R_M (fm)	$\frac{2J+1}{2J_0+1}\Gamma_0$ (eV)
1.60 ± 0.02	91 ± 7	158 ± 15	$\frac{1}{2}$	$\frac{7}{2}+$	$\frac{5}{2}+$	2.7	0.078	$2.4_{-0.4}^{+0.3}$	$0.055_{-0.012}^{+0.014}$
5.77 ± 0.04	27 ± 3	38 ± 8	$\frac{1}{2}$	$(\frac{3}{2}+)$	$(\frac{3}{2}+)$	2.4	0.83	$2.0_{-1.5}^{+0.6}$	$0.61_{-0.23}^{+0.28}$
7.03 ± 0.05	13 ± 4	42 ± 8	$\frac{1}{2}$	$(\frac{5}{2}+)$	$(\frac{3}{2}+)$	3.8	2.9	3.7 ± 0.5	$2.2_{-0.8}^{+1.0}$
7.81 ± 0.03	59 ± 4	100 ± 10	$\frac{3}{2}$	$\frac{5}{2}+$, $\frac{3}{2}+$	$\frac{3}{2}+$	2.9	6.5	$2.6_{-0.4}^{+0.2}$	$4.7_{-1.0}^{+1.2}$
10.43 ± 0.05	39 ± 6	104 ± 15	$(\frac{3}{2})$	( )[a]	( )[a]	3.7	22	3.5 ± 0.3	17 ± 5
11.37 ± 0.07	34 ± 8	68 ± 15	$(\frac{3}{2})$	( )[a]	( )[a]	3.3	16	$3.0_{-0.8}^{+0.6}$	12_{-5}^{+6}
11.76 ± 0.06	41 ± 8	87 ± 16	$(\frac{3}{2})$	( )[a]	( )[a]	3.4	24	$3.2_{-0.6}^{+0.4}$	18_{-6}^{+7}

[a] $\frac{3}{2}+$, $\frac{5}{2}+$, or $\frac{7}{2}+$.

counting statistics and in the position of the baseline. The values given for Γ_0 include additional uncertainties, principally in the three radiative corrections and in the counter efficiency. Since the latter uncertainties essentially cancel out in the calculations of R_M, the uncertainties given for this quantity are obtained from those for the cross sections.

As mentioned earlier, our experimental results are compared with a theory based on the plane-wave Born approximation,[6] but are subjected to a correction based on the DWBA. Chertok and Johnson[13] have calculated the DWBA correction for the case of 180° magnetic scattering. Their calculation of Γ_0 for the 10.63-MeV $M1$ transition in ^{26}Mg showed the DWBA value to be 25% lower than the plane-wave value. The values in Table I are based on the DWBA corrections of Chertok and Johnson for this level, slightly altered to account for the momentum transfer used in this experiment. We have therefore divided each 56-MeV experimental cross section by 1.085, and each 39-MeV value by 1.242. The subsequent processing, using Eqs. (1)–(3), results in reduced values for both R_M and Γ_0.

It should be mentioned that the DWBA calculations are based on the theoretical work of Tuan *et al.*,[14] who only take into account nuclear currents and not magnetization density. In the work of Drechsel[9] the magnetization density is included; however, a program for computing the correction coefficients is not yet available. Estimates of the error in the *correction* by Chertok[15] resulting from the neglect of the magnetization density are no more than 25% for our case.

IV. DISCUSSION

By far the most intense inelastic peak in the spectra corresponding to either bombarding energy is that at 1.60 MeV. This results from the excitation of the first excited state ($\frac{7}{2}+$) of the $K=\frac{5}{2}+$ ground-state rotational band, via an $M1$ transition. Although many other levels in the 0–5.5-MeV region of the appropriate spin and parity are available through $M1$ transitions, our data clearly indicate that they are inhibited. Since all of the other bands in this region are $K=\frac{1}{2}+$ bands, our results therefore support the $\Delta K=0, \pm1$ selection rule.

The ground-state radiation width for the 1.60-MeV excitation is found to be $0.041_{-.009}^{+.011}$ eV (see Table I). The lifetime for the decay of this excited state has been measured by Sharpey-Schafer *et al.*[16] and by Rasmussen *et al.*[17] using proton-inelastic-scattering and resonance-fluorescence techniques, respectively. Their values agree closely. Sharpey-Schafer *et al.* give the $E2$ and $M1$ contributions in the decay and find for the latter a width of 0.026 ± 0.005 eV. The upper uncertainty limit of this value is slightly below our lower limit. We cannot explain this discrepancy. A possible small $E2$ contribution in the excitation, which we neglect in our analysis, could only partially account for our value being higher.

The peaks at 5.77 and 7.03 MeV are identified with levels at 5.786 and 7.028 MeV reported from (d, p) and (d, α) reactions.[2,3,18] The transition radius found for the 5.77-MeV peak is somewhat small; however, our analysis clearly favors it resulting from an $M1$ transition. Since our analysis indicates that both peaks result from $M1$ transitions, the two levels may be members of a $K=\frac{3}{2}+$ band, based on the $d_{3/2}$ single-particle state, which is expected to have about a 5-MeV separation from the $d_{5/2}$ ground state.

The fact that the 7.81-MeV peak falls where an analog is energetically expected, along with the corroborative results of earlier workers,[19] leads us to identify

[13] B. T. Chertok and W. T. K. Johnson, Phys. Rev. Letters **22**, 67 (1969).
[14] S. Tuan, L. Wright and D. Onley, Nucl. Instr. Methods **60**, 70 (1968).
[15] B. T. Chertok Phys. Rev. **187**, 1340 (1969).
[16] J. F. Sharpey-Schafer, R. W. Ollerhead, A. J. Ferguson, and A. E. Litherland, Can. J. Phys. **46**, 2039 (1968).
[17] V. K. Rasmussen, F. R. Metzger, and C. P. Swann, Phys. Rev. **123**, 1386 (1961).
[18] P. M. Endt and C. Van der Leun, Nucl. Phys. **A105**, 1 (1967).
[19] J. C. Hardy and D. J. Skyrme, Bull. Am. Phys. Soc. **11**, 627 (1966).

this peak as a composite of the $T=\frac{3}{2}$ analogs of the unresolved ground- and first-excited states of ^{25}Na. As indicated in Fig. 4, these states have assignments of $\frac{5}{2}^+$ and $\frac{3}{2}^+$, respectively, and belong to a $K=\frac{3}{2}^+$ rotational band.[5] As a result of interband mixing in the case of the $\frac{5}{2}^+$ state, there is a reversal in the order of the spins in the band caused by the repulsion from other $\frac{5}{2}^+$ states in the nearby $K=\frac{5}{2}^+$ and possibly $K=\frac{1}{2}^+$ bands.[5] A value of $\Gamma_0=0.82$ eV is given by Morrison *et al.*[5] in their work on the ^{24}Mg$(p,\gamma)^{25}$Al reaction for the $(\frac{3}{2}, \frac{5}{2}^+, \frac{3}{2}^+)\rightarrow(\frac{1}{2}, \frac{5}{2}^+, \frac{5}{2}^+)$ transition in ^{25}Al. Under the assumption that the Γ_0's are the same for corresponding ^{25}Al and ^{25}Mg levels (with the exception of an ω^3 factor), we use their value in conjunction with our value of $[(2J+1)/(2J_0+1)]\Gamma_0=4.74$ eV for the composite 7.81-MeV peak in ^{25}Mg to obtain $\Gamma_0=5.9$ eV for the $(\frac{3}{2}, \frac{3}{2}^+, \frac{3}{2}^+)\rightarrow(\frac{1}{2}, \frac{5}{2}^+, \frac{5}{2}^+)$ transition in ^{25}Mg. Morrison *et al.* applied the same technique to find the corresponding value of Γ_0 in ^{25}Al which they then used[20] in a comparison of the experimental results with the Nilsson model.

This comparison was made using the Nilsson-model expression for the $M1$ transition strength of an interband transition $I_1K_1\rightarrow I_2K_2$. It is given by[21]

$$B_{M1}(I_1\rightarrow I_2) \propto (I_1 1 K_1 K_2-K_1 \mid I_2K_2)^2 \times \langle\psi_{K_2} \mid Q_{K_2-K_1} \mid \psi_{K_1}\rangle^2, \quad (4)$$

where $\langle\psi_{K_2} \mid Q_{K_2-K_1} \mid \psi_{K_1}\rangle$ is the reduced $M1$ matrix element between the two states. The rate of such an interband transition is thus proportional to the square of the Clebsch-Gordan coefficient in Eq. (4), apart from the ω^3 factor. A meaningful comparison with the theory is thus afforded by considering the ratio of transition rates to the ground state from the two $T=\frac{3}{2}$ states, which the theory predicts is[5]

$$\frac{\mid M \mid^2(\frac{3}{2}, \frac{5}{2}^+, \frac{3}{2}^+\rightarrow\frac{1}{2}, \frac{5}{2}^+, \frac{5}{2}^+)}{\mid M \mid^2(\frac{3}{2}, \frac{3}{2}^+, \frac{3}{2}^+\rightarrow\frac{1}{2}, \frac{5}{2}^+, \frac{5}{2}^+)}=0.29.$$

If our experimental value and that of Morrison *et al.* are used to determine the width for the $\frac{3}{2}^+$ state, the experimental value is $0.13_{-0.07}^{+0.12}$. The theoretical result is probably somewhat high because it assumes the same fraction of $K=\frac{3}{2}$ band in both $T=\frac{3}{2}$ states. As mentioned earlier the mixing is probably greater for the lower of the two states because of contributions from the $K=\frac{5}{2}^+$ and possibly $K=\frac{1}{2}^+$ bands. Since these admixtures cannot contribute to the transition to the $T=\frac{1}{2}$, $K=\frac{5}{2}^+$ ground state, the strength of this transition should be diminished relative to that from the $\frac{3}{2}^+$ upper $T=\frac{3}{2}$ state which is essentially pure. Thus the comparison of these experimental results with the theory is considered more favorable than that afforded

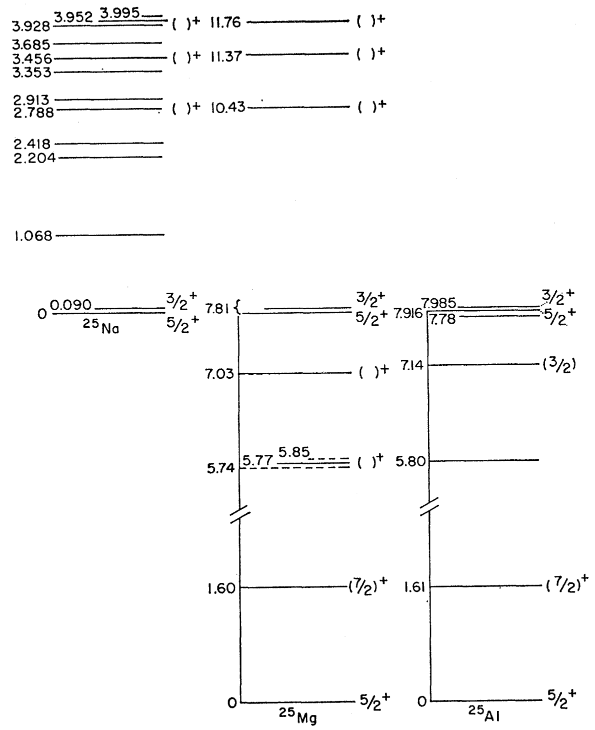

FIG. 4. Energy-level diagram adjusted for the Coulomb displacement showing ^{25}Na, ^{25}Mg, and ^{25}Al analog states. In the ^{25}Mg scheme only states excited and analyzed in this work are shown with solid lines. Some corresponding ^{25}Al states are shown. Energy values given in the ^{25}Na and ^{25}Al level schemes are those quoted from Ref. 18 except for the 7.916- and 7.985-MeV levels quoted from Ref. 5.

by the results of Teitelman and Temmer,[22] which lead to a value of 0.79 ± 0.12 for the above ratio.[23]

Our analysis also indicates that the three highest-energy peaks considered here, at 10.43, 11.37, and 11.76 MeV also arise from $M1$ transitions. Thus, the values of J^π and K^π can range from $\frac{3}{2}^+$ to $\frac{7}{2}^+$. Despite the subtraction of the 8% contribution from ^{24}Mg, some structure at about 9.9 MeV still remains, but it was not considered strong enough to justify quantitative treatment. However, a level at this energy would be in close alignment with the 2.204-MeV level in ^{25}Na. Also the levels at 10.43, 11.37, and 11.76 MeV, shown in Fig. 4, align reasonably well with the ^{25}Na levels at 2.788, 3.456, and 3.952 MeV, respectively. Since the spacing of these levels seems to correspond closely to that of levels in ^{25}Na, we tentatively identify these also as $T=\frac{3}{2}$ analog states. It should be emphasized that our level of confidence in the values of Γ_0 and R_M derived from these three higher-energy peaks is somewhat lower than in those corresponding to the peaks at lower energies due to the increasing uncertainty in the baseline position with increasing excitation energy.

[20] Because of a change in our final analysis, this result is now 6.3 and not 5.76 eV as used by Morrison *et al.*

[21] A. K. Kerman, in *Nuclear Reactions*, edited by P. M. Endt and M. Demeur (North-Holland Publishing Co., Amsterdam, 1959), Vol. 1, p. 427.

[22] B. Teitelman and G. M. Temmer, Phys. Letters **26B**, 371 (1968).

[23] A more complete discussion of this comparison is given in Ref. 5.

The foregoing results are clearly consistent with the rotational character of this nucleus, well established for the 0–5-MeV excitation region. They are also consistent with such an interpretation above this energy, including the first two $T=\frac{3}{2}$ states first discussed on this basis by Morrison *et al.*[5] Whether the highest four levels discussed can be so interpreted is not clear at this time. It is also felt that our results indicate the potential usefulness of 180° electron scattering as a complement to other approaches in the investigation of rotational characteristics in odd-A nuclei.

Note added in proof. Recent threshold neutron work with the $^{26}Mg(\gamma, n)^{25}Mg$ reaction by Berman, Baglin, and Bowman (unpublished) has come to our attention. With better energy resolution, their work suggests the possibility that $\Delta T=0$, $M1$ transitions may be contributing to some of the peaks discussed as tentatively corresponding to $T=\frac{3}{2}$ levelz. There is reasonable evidence that this is not happening in the case of the 7.81-MeV peak. However, we cannot eliminate this possibility for peaks at greater excitation energies.

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Study of the Low-Lying Excited States of Al^{29} II: $Al^{27}(t,p\gamma)Al^{29}$ and $Si^{30}(t,\alpha\gamma)Al^{29}$ Angular Correlation Investigation*

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The low-lying excited states of Al^{29} have been investigated by measuring γ-ray angular correlations in a collinear geometry. The levels were populated in the $Al^{27}(t,p\gamma)Al^{29}$ and $Si^{30}(t,\alpha\gamma)Al^{29}$ reactions at triton bombarding energies of 2.8 and 2.5 MeV, respectively. The γ-ray branching ratios for states up to 3.7-MeV excitation energy were obtained. Spin assignments, or limits on the spins, for the first six excited states have been deduced on the basis of these data combined with previous results: $[E_x, J^\pi]$; 1.40 MeV, $\frac{1}{2}^+$; 1.76 MeV, $(\frac{1}{2})$, $\frac{3}{2}$, $\frac{5}{2}$, $\frac{7}{2}$; 2.23 MeV, $\frac{3}{2}$, $\frac{5}{2}$, $\frac{7}{2}$; 2.88 MeV, $\frac{3}{2}^+$; 3.07 MeV, $(\frac{3}{2}^+)$, $\frac{5}{2}^+$; and 3.19 MeV, $(\frac{3}{2})$, $\frac{5}{2}^{(-)}$, $\frac{7}{2}^{(-)}$, $(\frac{9}{2})$.

I. INTRODUCTION

A RECENT investigation by Jones[1] of the differential cross section of the $Si^{30}(t,\alpha)Al^{29}$ reaction at the incident triton energy $E_t=11.8$ MeV has resulted in information on the states of Al^{29} up to 4.41-MeV excitation energy. The characteristic α-particle angular distributions were interpreted to enable definite spin-parity assignments of $J^\pi=\frac{1}{2}^+$ to be made to both the 1.402- and 3.434-MeV levels in Al^{29}. Restrictions were also placed on possible spin-parity values of several other levels. A summary of the available information on Al^{29} excited states, including these results, is presented in Ref. 1. In the present work,[2] further information on the excited states of Al^{29} is reported, *viz.*, the γ-ray branchings of low-lying levels with excitation energy $E_x\leq 3.7$ MeV, and information about the spins and γ-ray transition multipolarities for states with $E_x\leq 3.19$ MeV. These results were deduced from measurements of γ-ray angular distributions from decaying residual nuclei aligned in a nuclear reaction.[3] States in Al^{29} were populated in both the $Al^{27}(t,p\gamma)Al^{29}$ reaction ($Q=8.68$ MeV) and the $Si^{30}(t,\alpha\gamma)Al^{29}$ reaction ($Q=6.22$ MeV), at bombarding energies of 2.8 and 2.5 MeV, respectively. The γ-ray angular distributions were obtained by measuring the yield of γ rays at angles between $\theta_\gamma=0°$ and 90° in coincidence with reaction produced protons—when investigating the $Al^{27}(t,p\gamma)Al^{29}$ reaction—or α particles when investigating the $Si^{30}(t,\alpha\gamma)Al^{29}$ reaction. The reaction particles were detected in an annular counter located near 180° with respect to the incident beam direction. Because of the angular symmetry involved when the outgoing reaction particle is detected at 180°, γ decays are observed from Al^{29} states with only magnetic substates $|m|=\frac{1}{2}$ populated as a result of the $Si^{30}(t,\alpha)Al^{29}$ reaction, while in contrast, substates with values of $|m|$ from $\frac{1}{2}$ through $\frac{7}{2}$ can be populated in the $Al^{27}(t,p)Al^{29}$ reaction. In practice, these results are modified to the extent that higher magnetic sub-

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[1] A. D. W. Jones, Phys. Rev. **180**, 997 (1969).

[2] Preliminary accounts of the work have previously been reported in Bull. Am. Phys. Soc. **13**, 674 (1968); **13**, 1372 (1968).

[3] A. E. Litherland and A. J. Ferguson, Can. J. Phys. **52**, 788 (1961).