Shapes of (^{6}Li,d) Angular Distributions as Signatures of Rotational Bands in ^{29}Si†

N. Anantaraman, J. P. Draayer,* H. E. Gove, and J. P. Trentelman
Nuclear Structure Research Laboratory, University of Rochester, Rochester, New York 14627
(Received 29 July 1974)

Angular distributions obtained in a study of the ^{25}Mg(^{6}Li,d) reaction at $E_{\rm Li}=36$ MeV are characterized by the lowest allowed L transfers for cluster transitions to the members of the ground-state rotational band of ^{29}Si, while a mixture of L values is required for states of the $K=\frac{3}{2}^+$ excited band. This demonstrates that an α-transfer reaction can probe the internal structure of the nucleus in a way that can be deciphered.

The (^{6}Li, d) reaction on even-even sd- and fp-shell targets at bombarding energies above the Coulomb barrier exhibits angular distributions characteristic of the transferred orbital angular momentum L.[1,2] The reaction has been less well studied on odd-A nuclei, where it is of interest because for $J_{\rm initial}$ and $J_{\rm final}\neq\frac{1}{2}$ more than one L value can contribute to a transition and the contributions of the various L's can be separated. This is because the angular distributions are sensitive to L and the magnitudes of the cross sections do not vary greatly with L. The reaction thus provides a sensitive probe with which to study the structure of the final states populated. For instance, calculations[3] for α transfer on light nuclei predict spectroscopic strengths for the various L transfers to final states of the same J^π that depend on the structures of the states concerned. The present Letter reports on a study of the reaction ^{25}Mg(^{6}Li, d) which shows angular distributions which differ significantly for states of the same J^π in ^{29}Si.

Self-supporting targets enriched to over 99% in ^{24}Mg and in ^{25}Mg and about 100 μg/cm^2 thick were bombarded with a 36-MeV ^{6}Li beam of about 300 nA from the Rochester University MP tandem accelerator. Outgoing deuterons were momentum analyzed by an Enge split-pole spectrograph and detected in photographic emulsions. The energy resolution was about 70 keV. Absolute cross sections were obtained by comparing the elastic scattering yield measured in a monitor counter to the results obtained by Schumacher *et al.*[4] for the scattering of 36-MeV ^{6}Li from ^{26}Mg.

The reaction ^{24}Mg(^{6}Li, d) leading to the members of the ground-state rotational band of ^{28}Si served to give the experimental shapes of pure $L=0$, 2, and 4 angular distributions. The $L=0$ and 2 angular distributions, shown respectively in Figs. 1 and 2, were fitted well by both zero-range and exact, finite-range[5] distorted-wave Born-approximation (DWBA) calculations assuming a cluster-transfer mechanism and gave relative spectroscopic factors in good agreement with SU(3) predictions; the solid lines in the figures represent the zero-range DWBA fits. The $L=4$ distribution could not be well fitted despite the use of a wide range of bound-state and optical-model parameters: The "best-fit" calculated curve peaked several degrees forward of the experimental peak at $\theta_{\rm c.m.}=27°$, a feature also observed in our analyses of ^{16,18}O(^{6}Li, d) reactions.[6]

There does not appear to be a simple picture that adequately describes the low-lying states of ^{29}Si,[7] but the rotational-model interpretation[8] provides a framework in which to discuss the results of the ^{25}Mg(^{6}Li, d)^{29}Si experiment. In this model, the $\frac{1}{2}^+$(0.0 MeV), $\frac{3}{2}^+$(2.43 MeV), $\frac{5}{2}^+$(2.03 MeV), and $\frac{9}{2}^+$(4.74 MeV) states of ^{29}Si are assumed to belong to an oblate $K=\frac{1}{2}^+$ rotational

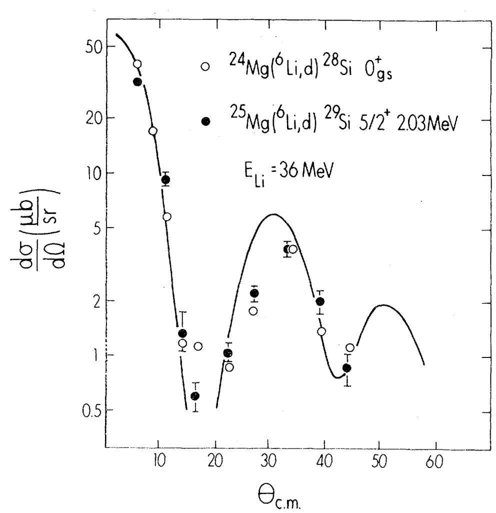

FIG. 1. Comparison of the (^{6}Li,d) $L=0$ transition to the ground state of ^{28}Si with the angular distribution for the $\frac{5}{2}^+$ state at 2.03-MeV excitation in ^{29}Si. The solid line represents a zero-range DWBA fit to the former reaction and the indicated cross sections refer to the latter. The ^{24}Mg(^{6}Li,d) cross sections are ≈ 2.5 times larger.

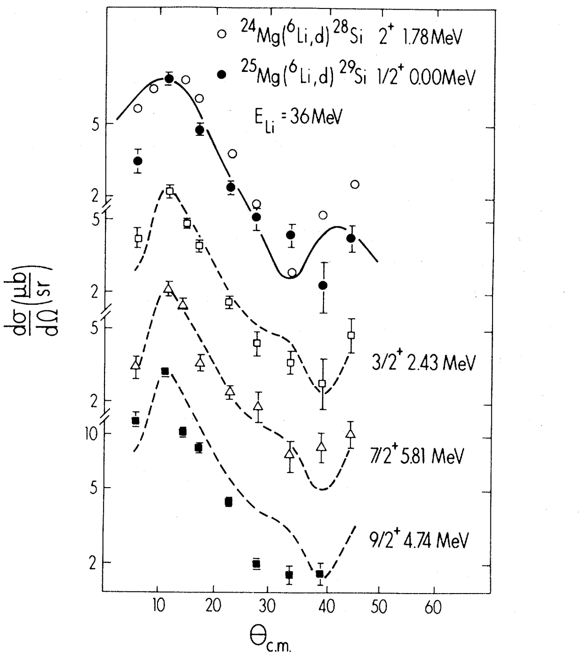

FIG. 2. Top, comparison of the $L=2$ (^{6}Li, d) angular distribution for the 2^+ state at 1.78-MeV excitation in ^{28}Si and the $\frac{1}{2}^+$ ground state of ^{29}Si. The solid line represents a zero-range DWBA fit to the former reaction. In the bottom three curves, angular distributions for the $\frac{3}{2}^+$(2.43 MeV), $\frac{7}{2}^+$(5.81 MeV), and $\frac{9}{2}^+$(4.74 MeV) states of ^{29}Si are compared with a smooth curve (dashed line) drawn through the experimental points for the transition to the $\frac{1}{2}^+$ state.

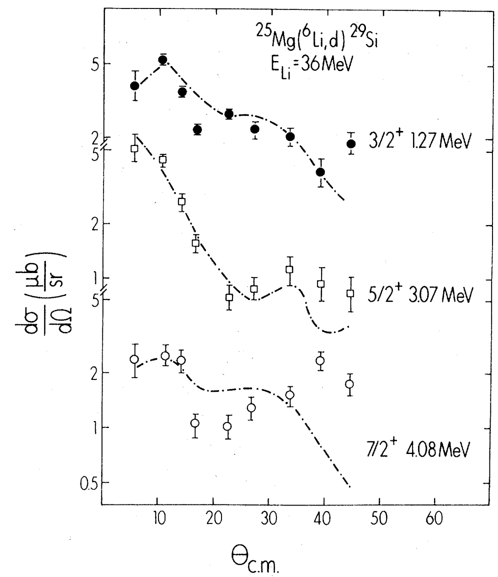

FIG. 3. Angular distributions for (^{6}Li,d) reaction leading to members of the $K=\frac{3}{2}^+$ rotational band of ^{29}Si. The dash-dotted lines for the $\frac{3}{2}^+$ and $\frac{7}{2}^+$ states are mixtures of pure $L=2$ and 4 experimental shapes, as discussed in the text, and the dash-dotted line for the $\frac{5}{2}^+$ state is a mixture of pure $L=0$ and 2 shapes.

band, while the $\frac{3}{2}^+$(1.27 MeV), $\frac{5}{2}^+$(3.07 MeV), $\frac{7}{2}^+$(4.08 MeV), $\frac{9}{2}^+$(5.65 MeV), and $\frac{11}{2}^+$(7.14 MeV) states belong to an oblate $K=\frac{3}{2}^+$ rotational band, probably with a substantial degree of band mixing.[9] None of the first four $\frac{7}{2}^+$ states is related to the $K=\frac{1}{2}^+$ band in a clear way.

The selection rules on angular momentum and parity allow a multiplicity of L values for the reaction ^{25}Mg(^{6}Li, d) to each final state in ^{29}Si except for $\frac{1}{2}^+$ states, which can be populated only by one L value ($L=2$ because the ground-state spin of ^{25}Mg is $\frac{5}{2}^+$). But it is found experimentally that the angular distribution for each member of the ground-state ($K=\frac{1}{2}^+$) band is that characteristic of a single L transfer, the L value being the lowest one allowed by the selection rules. This is shown in Fig. 1 for the $\frac{5}{2}^+$ state at 2.03-MeV excitation by comparing the angular distribution for the transition to this state with the pure $L=0$ distribution for the ground state of ^{28}Si in the reaction ^{24}Mg(^{6}Li, d) done at the same bombarding energy. Figure 2 compares the necessarily pure $L=2$ (^{6}Li, d) angular distributions for the 2^+ state of ^{28}Si and the $\frac{1}{2}^+$ (ground) state of ^{29}Si. It also compares the angular distributions for the $\frac{3}{2}^+$ and $\frac{9}{2}^+$ states of the ground-state rotational band and for the $\frac{7}{2}^+$ state at 5.81-MeV excitation (which may belong to that band, as discussed below) with the $L=2$ transition to the $\frac{1}{2}^+$ state; the dashed lines in the figure represent the same smooth curve drawn through the experimental points for the transition to the $\frac{1}{2}^+$ state. The results show that the transitions to the $\frac{3}{2}^+$, $\frac{7}{2}^+$, and $\frac{9}{2}^+$ states are all predominantly $L=2$ in character although the selection rules allow higher L transfers for them.

In sharp contrast, the angular distributions for the transitions to the members of the excited ($K=\frac{3}{2}^+$) band show a mixture of L values. The dash-dotted lines in Fig. 3 represent the results of a least-squares fitting to the angular distributions for the $\frac{3}{2}^+$ state at 1.27 MeV and the $\frac{7}{2}^+$ state at 4.08 MeV by a mixture of $L=2$ and 4 experimental shapes and for the $\frac{5}{2}^+$ state at 3.07 MeV by a mixture of $L=0$ and 2 shapes. The experimental $L=0$ and 4 shapes were taken from the reaction ^{24}Mg(^{6}Li, d) leading to the 0^+ and 4^+ states of the ground-state rotational band of ^{28}Si and the $L=2$ shape from the ^{25}Mg(^{6}Li, d) transition to the ground state of ^{29}Si. The fits obtained for the $\frac{3}{2}^+$ and $\frac{5}{2}^+$ states are satisfactory; for the $\frac{7}{2}^+$ state, the addition of an $L=6$ component may provide an adequate fit, but a pure $L=6$ shape was not available. The ratio of spectroscopic factors in which the $L=2$ and 4 components have been added is 1 : 0.73 for the $\frac{3}{2}^+$ state and 1 : 0.97 for the $\frac{7}{2}^+$ state; for the $\frac{5}{2}^+$ state, the ratio of $L=0$ and 2 spectroscopic factors is 1 : 0.34.

As mentioned above, there is no clear evidence that any of the first four $\frac{7}{2}^+$ states in ^{29}Si is a member of the ground-state band. However, if the systematics observed in the present experiment for the $\frac{1}{2}^+$, $\frac{3}{2}^+$, $\frac{5}{2}^+$, and $\frac{9}{2}^+$ states of this band, viz. (^{6}Li, d) angular distributions characterized by a single L value which is the lowest one allowed by the selection rules, hold for all members of the band, then Fig. 2 shows that the state at 5.81-MeV excitation is a candidate for the $\frac{7}{2}^+$ member of this band. (The $\frac{7}{2}^+$ state at 5.29 MeV could not be resolved from the $\frac{9}{2}^-$ state 30 keV away.)

The presence of mixed L's in the angular distribution for transitions to the excited-band members shows that the predominance of the lowest allowed L in the distributions for transitions to the ground-state band members is not due to kinematics. This is also borne out by DWBA calculations, which, in fact, predict a slight increase in the cross section with increasing L because of the mismatch between the incoming and outgoing angular momenta. So the suppression of the higher L's for transitions to the ground-state band and their occurrence for the excited band must reflect differences in the structures of these two bands. (In the cluster-transfer approximation, the nuclear structure would influence the shape of the angular distribution only by affecting the L admixing.) An attempt was made to explain the observed features of the "α" spectroscopic factors in terms of a simple SU(3) model in which it was assumed that the α transfers were between the dominant $(\lambda, \mu) = (6, 6)$ component in the ground state of ^{25}Mg and members of the oblate $(\lambda, \mu) = (1, 11)$ $K=\frac{1}{2}$ and $K=\frac{3}{2}$ bands of ^{29}Si. Band mixing was included. Agreement with the strikingly simple experimental results could not be obtained, which suggests that such a simple SU(3) interpretation is not applicable to ^{29}Si.

In conclusion, we observe that (^{6}Li, d) angular distributions to members of the ground-state band of ^{29}Si are characterized by single L transfers, whereas transitions to members of the $K=\frac{3}{2}^+$ excited band show a mixture of L values. This must be caused by a difference in the intrinsic structures of the individual members of these two bands; the considerable mixing between the bands demanded by other experimental evidence[9] does not seem to affect the simplicity of this result. No explanation for this feature occurs to us. The present work demonstrates that an α-transfer reaction can probe the internal structure of the nucleus in a way that can be deciphered. It would be of great interest to see whether the angular distributions for (^{6}Li, d) reactions on other odd-mass nuclei similarly provide signatures for different bands.

†Work supported by a grant from the National Science Foundation.

*Work supported by the U. S. Atomic Energy Commission.

[1]K. Bethge, Ann. Rev. Nucl. Sci. 20, 255 (1970).

[2]U. Strohbusch, C. L. Fink, B. Zeidman, R. G. Markham, H. W. Fulbright, and R. N. Horoshko, Phys. Rev. C 9, 965 (1974).

[3]M. Ichimura, A. Arima, E. C. Halbert, and T. Terasawa, Nucl. Phys. A204, 225 (1973); D. Kurath, Phys. Rev. C 7, 1390 (1973); D. Kurath and I. S. Towner, Nucl. Phys. A222, 1 (1974); J. P. Draayer, to be published.

[4]P. Schumacher, N. Ueta, H. H. Duhm, K.-I. Kubo, and W. J. Klages, Nucl. Phys. A212, 573 (1973).

[5]R. M. DeVries, Phys. Rev. C 8, 951 (1973).

[6]N. Anantaraman, R. M. DeVries, J. P. Draayer, H. E. Gove, and J. P. Trentelman, Bull. Amer. Phys. Soc. 19, 471 (1974).

[7]B. H. Wildenthal and J. B. McGrory, Phys. Rev. C 7, 714 (1973).

[8]D. A. Bromley, H. E. Gove, and A. E. L. Litherland, Can. J. Phys. 35, 1057 (1957).

[9]S. I. Baker and R. E. Segel, Phys. Rev. 170, 1046 (1968).