

test various α -cluster models² of ^{16}O and provide additional measurements of α -widths needed for astrophysical calculations.

- 1) F.D. Becchetti, D. Overway, J. Janecke, and W.W. Jacobs, Nucl. Phys. A344, 336 (1980).
- 2) D. Overway, F.D. Becchetti, and J. Janecke, 4th International Conference Chester, England, July 1984, p. 101.

SEARCH FOR HIGH SPIN STATES IN ^{27}Al AND ^{27}Si

Z.-J. Cao, R.D. Bent and H. Nann
Indiana University Cyclotron Facility, Bloomington, Indiana 47405

J.D. Brown
Princeton University, Princeton, New Jersey 08540

Previous studies¹ of the $A(p, \pi^-)A+1$ reaction have demonstrated the high selectivity of the reaction for states in the residual nucleus which are presumed to have a stretched or nearly stretched two-particle one-hole configuration with respect to the target nucleus. This feature of the (p, π^-) reaction has been observed for both light and heavy nuclei¹ and for two cases in the sd-shell: $^{18}\text{O}(p, \pi^-)^{19}\text{Ne}$ and $^{26}\text{Mg}(p, \pi^-)^{27}\text{Si}$.² Studies throughout the lower half of the sd-shell are in progress.³ To increase the reliability of the (p, π^-) reaction as a spectroscopic tool in the sd-shell, it is necessary to obtain, for at least a few cases, independent evidence regarding the spin structure of the states preferentially populated in the (p, π^-) reaction.

It has been observed that the $^{26}\text{Mg}(p, \pi^-)^{27}\text{Si}$ reaction populates selectively and strongly two excited states in ^{27}Si at excitation energies of 7 MeV and 9.5 MeV. These states have been tentatively assigned $13/2^+$ spin and parity. This is the highest spin possible if all the active nucleons are restricted to the sd-shell. Recent shell model calculations⁴ predict a $13/2^+$ state in ^{27}Si at an excitation energy between 7 and 8 MeV and

several high spin states around 10 MeV excitation energy.

To date there is little experimental evidence for high spin states in ^{27}Si besides that provided by the (p, π^-) reaction. The $^{27}\text{Al}(^3\text{He}, t)^{27}\text{Si}$ reaction is expected to populate the presumed stretched two-particle one-hole states seen in the $^{26}\text{Mg}(p, \pi^-)^{27}\text{Si}$ reaction, and the $^{24}\text{Mg}(\alpha, p)^{27}\text{Al}$ reaction can populate the mirror states in ^{27}Al . We have studied these two reactions in order to obtain supporting evidence for the high spin assignments inferred from the (p, π^-) reaction.

We measured the angular distributions of the $^{24}\text{Mg}(\alpha, p)^{27}\text{Al}$ and $^{27}\text{Al}(^3\text{He}, t)^{27}\text{Si}$ reactions using the Princeton AVF (K=60) cyclotron and Quadrupole-Three Dipoles (Q3D) magnetic spectrograph. The angular distributions of the reaction $^{26}\text{Mg}(^3\text{He}, t)^{26}\text{Al}$ leading to the known 5^+ (g.s.), 0^+ (0.228 MeV), and 3^+ (0.417 MeV) states were also measured in order to calibrate the "L-signature" for possible high spin state transitions in the $^{27}\text{Al}(^3\text{He}, t)^{27}\text{Si}$ reaction.

The spectra obtained from the $^{24}\text{Mg}(\alpha, p)^{27}\text{Al}$ and $^{27}\text{Al}(^3\text{He}, t)^{27}\text{Si}$ reactions at bombarding energies of

48.2 and 29.8 MeV, respectively, and a scattering angle of 15° , for the excitation energy region around 7 MeV and 9.5 MeV where the strongly populated residual states were observed in the $^{26}\text{Mg}(p,\pi^-)^{27}\text{Si}$ reaction, and selected angular distributions, are displayed in Figs. 1-4. The angular distributions of the

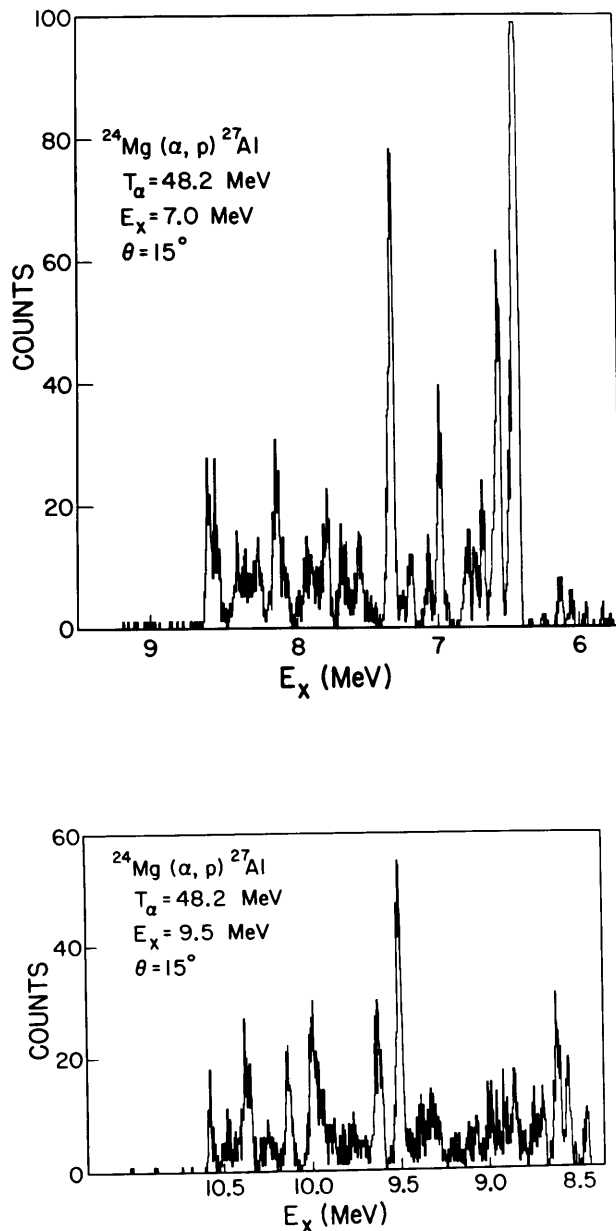


Figure 1. Spectrum from the $^{24}\text{Mg}(\alpha,p)^{27}\text{Al}$ reaction at a bombarding energy of 48.2 MeV and a scattering angle of 15° for the excitation energy region around 7 MeV (a) and 9.5 MeV (b).

$^{26}\text{Mg}(^3\text{He},t)^{26}\text{Al}$ reaction at 29.7 MeV bombarding energy leading to 5^+ , 0^+ and 3^+ states are shown in Fig. 5. The energy resolution for these measurements, which is determined mainly by the target thickness, is less than 30 keV.

Zero-range DWBA calculations have been made for the $^{24}\text{Mg}(\alpha,p)^{27}\text{Al}$ reaction (Fig. 2). A cluster (triton) transfer to the sd-shell was assumed to form the same stretched states as those seen in the (p,π^-) reaction. The alpha and proton optical potential parameters were taken from the compilation of Perey.⁵ The known $11/2^+$ (6.483 MeV) and $9/2^+$ (7.170 MeV) states were used to calibrate the DWBA calculations. We note that the DWBA calculations with cluster orbital angular momentum transfers of $L=6$ and $L=4$ reproduce the data for the $11/2^+$ and $9/2^+$ states reasonably well [Figs. 2(a),(b)]. The same optical model parameters can then be used with some confidence for other transitions. The results show that the 9.599 MeV transition may have $L=6$ [Fig. 2(d)], so that this state is a candidate for a $13/2^+$ assignment. The 6.885 MeV transition appears to involve a mixture of $L=4$ and $L=6$ [Fig. 2(c)].

There is evidence that the $(^3\text{He},t)$ reaction mechanism is direct even at bombarding energies as low as 26 MeV.⁶ By comparing the shapes of the angular distributions for the $^{27}\text{Al}(^3\text{He},t)^{27}\text{Si}$ reaction (Fig. 4) to those of the calibration reaction $^{26}\text{Mg}(^3\text{He},t)^{26}\text{Al}$ (Fig. 5), we make the following tentative spin assignments to various states in ^{27}Si . The transitions to the 6.723 MeV and 7.052 MeV states appear to have $L=2$, which is in agreement with the spin assignments for the isobaric analogue states in ^{27}Al at 6.885 MeV and 7.170 MeV ($9/2^+$), if we keep only $L=4$ instead of the mixture between $L=4$ and $L=6$. The angular distribution for the 6.981 MeV state in ^{27}Si is characteristic of an $L=0$ transition (we do not see a

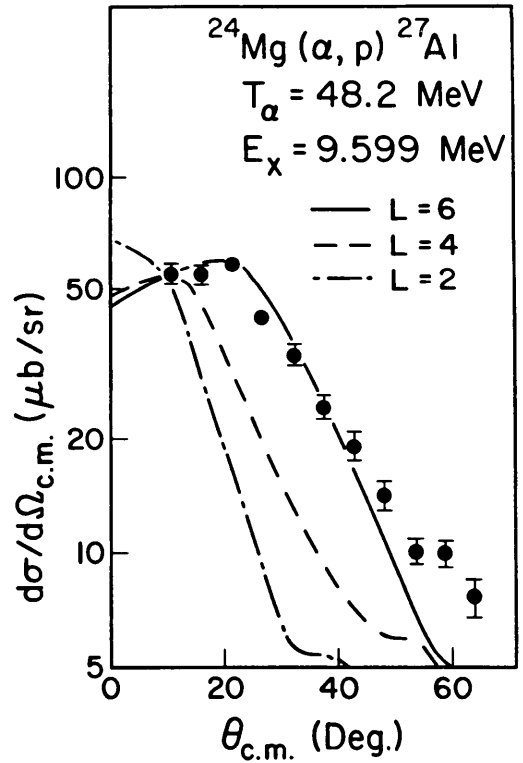
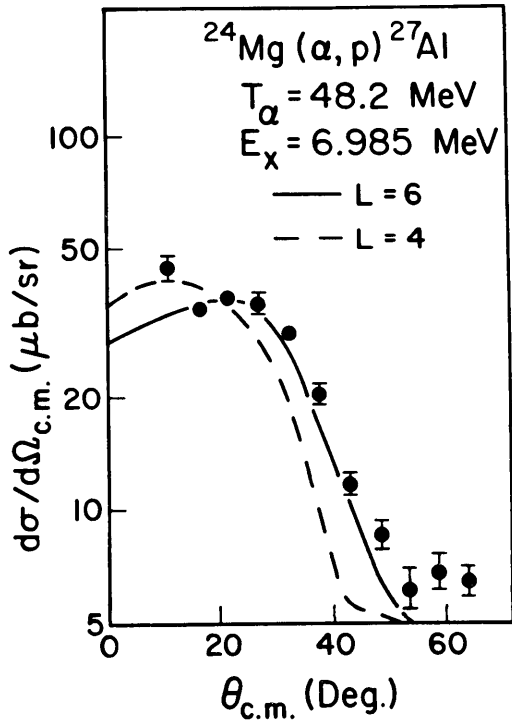
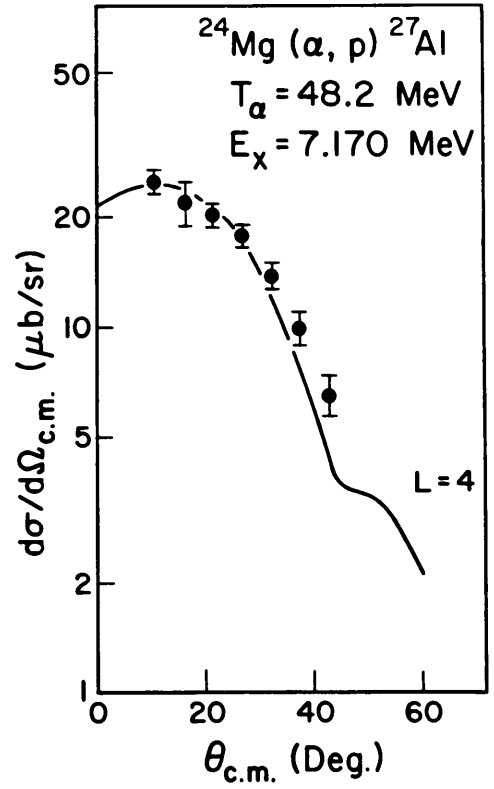
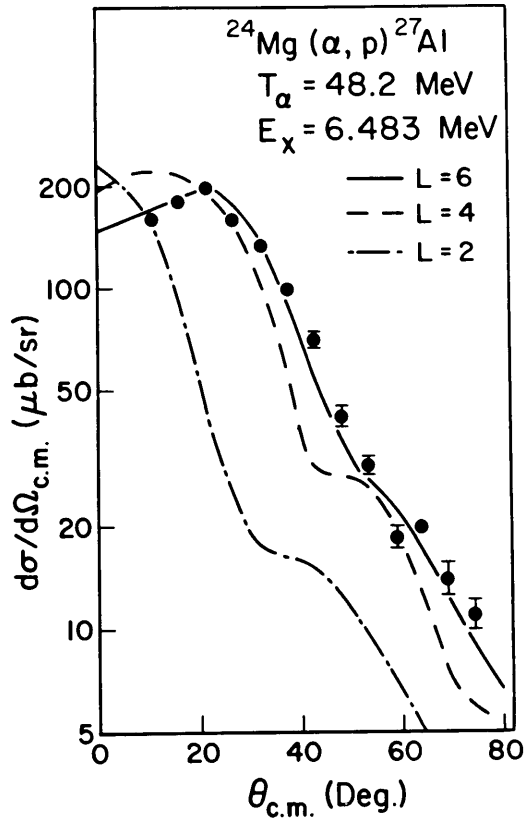


Figure 2. Angular distributions of the reaction $^{24}\text{Mg}(\alpha, p)^{27}\text{Al}$ at a bombarding energy of 48.2 MeV leading to states at 6.48 MeV (a), 7.17 MeV (b), 6.885 MeV (c), and 9.599 MeV (d). The curves are from zero-range DWBA calculations with cluster orbital angular momentum transfers of $L=2, 4$, and 6 .

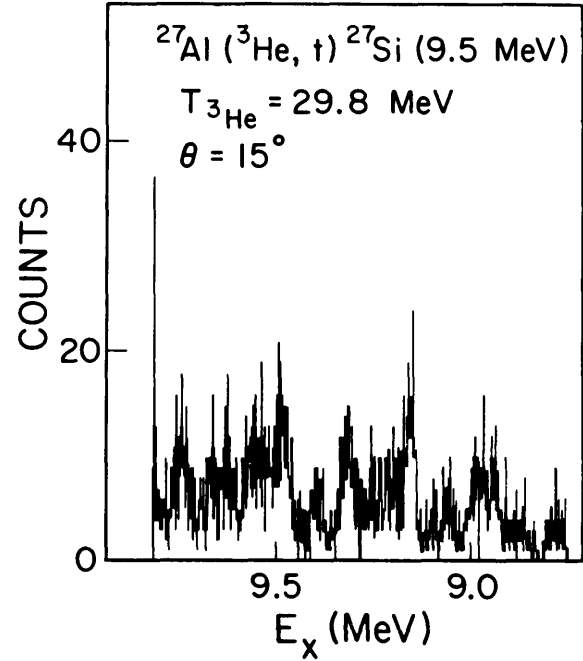
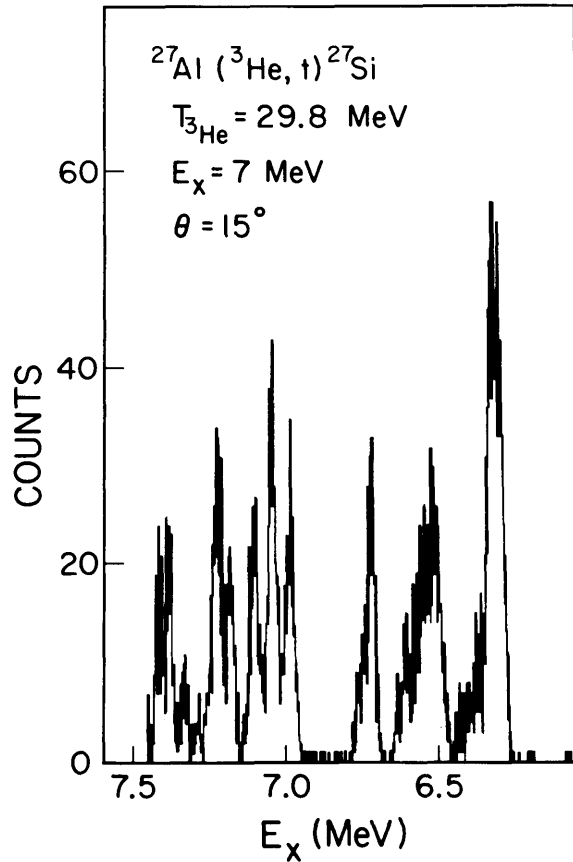


Figure 3. Spectrum from the $^{27}\text{Al}(^3\text{He},t)^{27}\text{Si}$ reaction at a bombarding energy of 29.8 MeV and a scattering angle of 15° for the excitation energy region around 7 MeV (a) and 9.5 MeV (b).

corresponding state in ^{27}Al). The angular distribution for the 7.124 MeV state in ^{27}Si is not fit by $L=0,2$ or 4. This is consistent with the failure of DWBA calculations for $L=2,4$ or 6 to fit the data for the 7.286 MeV state in ^{27}Al , which is the analogue of the ^{27}Si 7.124 MeV state. This implies that these states may have negative parity, resulting from the transfer of one nucleon into a higher shell. The 9.490 MeV state in ^{27}Si is the only candidate for $L=4$ transfer, and hence a possible $13/2^+$ spin and parity assignment. This is in agreement with the result of the DWBA calculation for the analogue 9.599 MeV state in ^{27}Al ;

however, there is considerable uncertainty due to the poor statistics and few data points for this state.

The $13/2^+$ assignment for the ^{27}Si 9.5 MeV state is supported by our earlier $^{27}\text{Al}(^3\text{He},t)^{27}\text{Si}$ data taken at IUCF using the QDDM spectrograph. In that experiment, we found only one state, at an excitation energy around 9.5 MeV, that stood out prominently when the scattering angle was increased from 12° to 20° ; however, the statistics were also poor for these data. The $(^3\text{He},t)$ reaction is not well suited for studies of high spin states because of the small linear momentum transfer.

On the basis of the empirical L-signatures for the

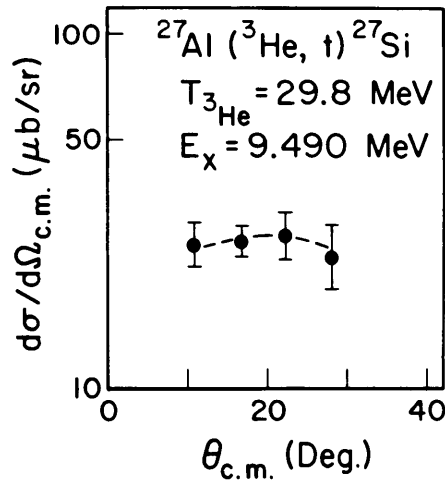
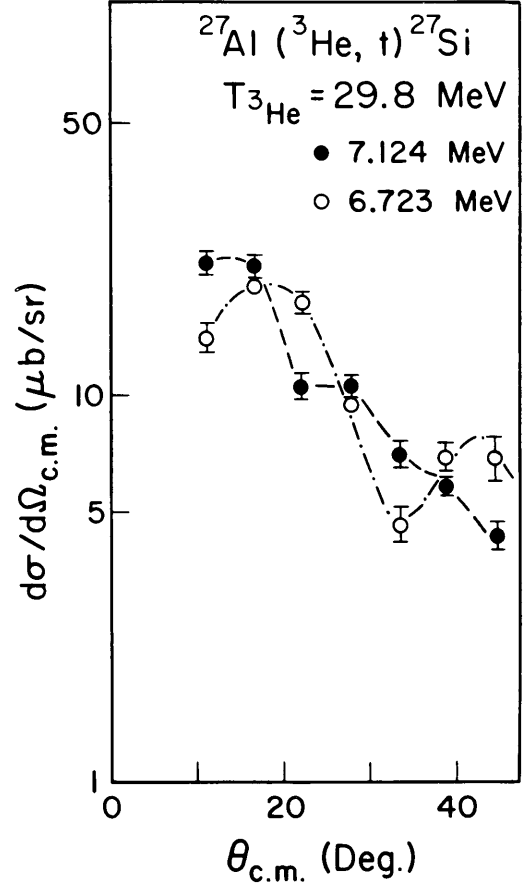
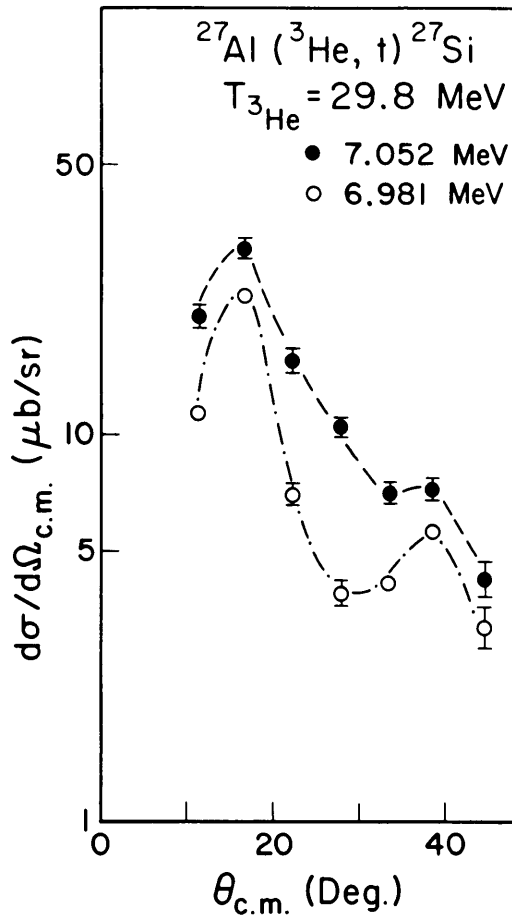


Figure 4. Angular distributions of the reaction $^{27}\text{Al}(^3\text{He}, t)^{27}\text{Si}$ at a bombarding energy of 29.8 MeV leading to states at 6.981 and 7.052 MeV (a), 6.723 and 7.124 MeV (b), and 9.490 MeV (c).

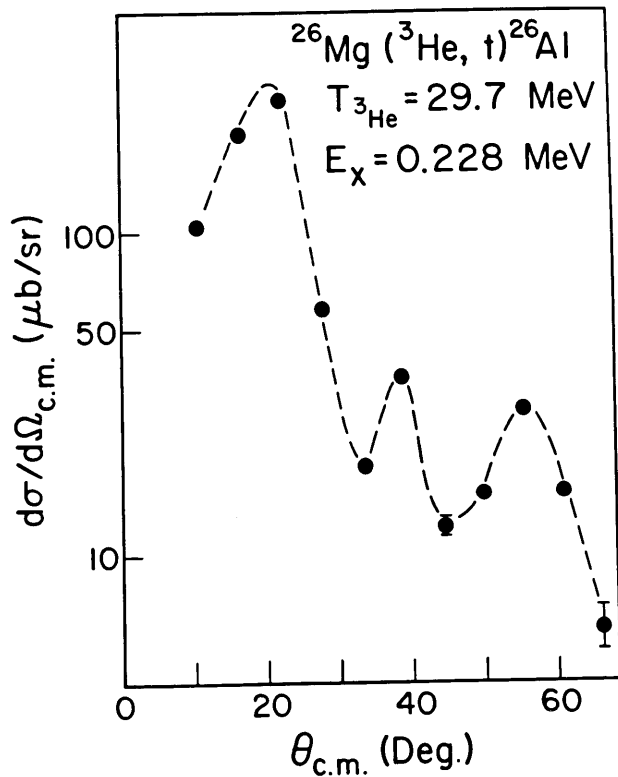
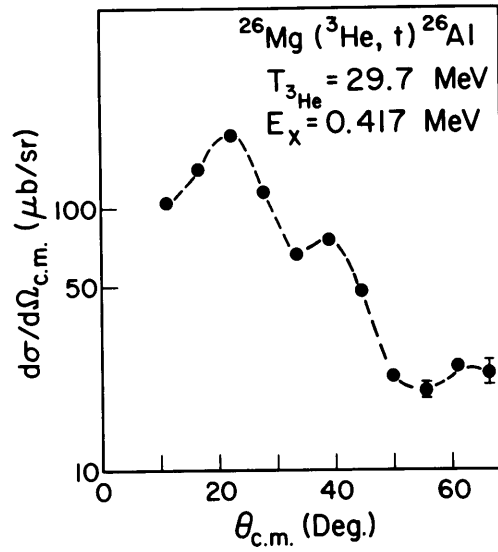
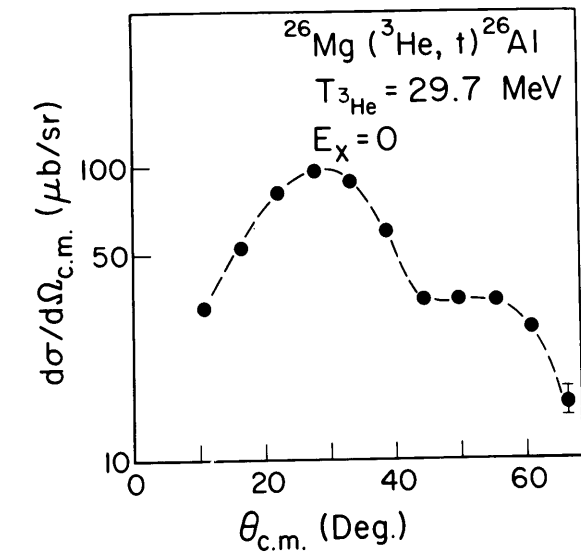


Figure 5. Angular distributions of the reaction $^{26}\text{Mg}(^3\text{He}, t)^{26}\text{Al}$ at a bombarding energy of 29.8 MeV leading to states at $E_x=0 \text{ MeV}$ (5^+), 0.228 MeV (0^+) and 0.417 MeV (3^+).

$^{27}\text{Al}(^3\text{He}, t)^{27}\text{Si}$ reaction and the zero-range DWBA calculations for the $^{24}\text{Mg}(\alpha, p)^{27}\text{Al}$ reaction, we find no evidence for a $13/2^+$ state near 7 MeV excitation energy in ^{27}Si , but possible evidence for such a state around 9.5 MeV.

- 1) S.E. Vigdor, Invited talk at the International Symposium on Nuclear Spectroscopy and Nuclear Interactions, Osaka, Japan (March, 1984).
- 2) J.J. Kehayias, Ph.D. Thesis, Indiana University, 1983; J.J. Kehayias, R.D. Bent, M.C. Green, M. Hugi, H. Nann and T.E. Ward, submitted for publication in Phys. Rev. C (1986).
- 3) Z-J. Cao, Ph.D. thesis work in progress, IUCF.
- 4) B.H. Wildenthal, private communication (1984).
- 5) C.M. Perey and F.G. Perey, Atomic Data and Nuclear Data Tables, 17, 1 (1976).
- 6) R. Sherr et al., Ann. Phys., 6, 548 (1971).