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

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We have studied the reactions ^{24}Mg(α,p)^{27}Al and ^{27}Al(^{3}He,t)^{27}Si to obtain independent evidence regarding the structure of states selectively populated in the ^{26}Si(p,π^-)^{27}Si reaction.

The A(p,π^-)A+1 reaction has been used recently[1] to locate and identify high-spin two-particle one-hole states in several sd-shell nuclei. To test the reliability of the (p,π^-) reaction as a spectroscopic tool, independent experimental confirmations of the spin assignments inferred from the (p,π^-) studies are needed.

It has been observed[2] that the ^{26}Mg(p,π^-)^{27}Si reaction selectively populates excited states in ^{27}Si at excitation energies of 7.0 and 9.5 MeV. Based on the strong population of these states and the pattern of the analyzing power angular distributions, they have been tentatively assigned 13/2$^+$ spin and parity. This is the highest spin two-particle one-hole configuration possible if all the active nucleons are restricted to the sd-shell. Recent shell model calculations[3] predict a 13/2$^+$ state in ^{27}Si around 7.0 MeV and several high-spin states in the E_x = 10 MeV region. To date there is little experimental evidence for high-spin states in ^{27}Si besides that provided by the (p,π^-) reaction.

To corroborate the high-spin assignments for the 7.0 and 9.5 MeV states in ^{27}Si inferred from the (p,π^-) studies,[2] we have studied the ^{27}Al(^{3}He,t)^{27}Si reaction, which can populate the same presumed stretched two-particle one-hole states seen in the ^{26}Mg(p,π^-)^{27}Si reaction, and the ^{24}Mg(α,p)^{27}Al reaction, which can populate the isobaric analogue states in ^{27}Al. A strong selectivity for high-spin states is expected for the latter reaction due to the large momentum transfer. We present here the angular distributions of the differential cross sections for both reactions and several states in the 7.0 and 9.5 MeV excitation energy regions, and discuss the evidence these data provide regarding spin and parity assignments for the observed states.

A 48.2 MeV ^{4}He beam and a 29.8 MeV ^{3}He beam from the Princeton AVF (k = 60) cyclotron were used to measure the angular distributions of the ^{24}Mg(α,p)^{27}Al and ^{27}Al(^{3}He,t)^{27}Si reactions. The angular distributions for the ^{26}Mg(^{3}He,t)^{26}Al reaction leading to the known 5$^+$ (0.0 MeV), 0$^+$ (0.228 MeV), and 3$^+$ (0.417 MeV) states were also measured in order to calibrate the "J-signature" for possible high-spin transitions in the ^{27}Al(^{3}He,t)^{27}Si reaction.

The reaction products were momentum analyzed with the Princeton Quadrupole-Three Dipole (Q3D) magnetic spectrograph and were detected in the focal plane with a resistive wire gas proportional counter followed by a scintillator. The Q3D spectrometer and its detection system have been described in detail elsewhere.[4]

Figs. 1 and 2 show the 15^{o} spectra obtained from the ^{24}Mg(α,p)^{27}Al and ^{27}Al(^{3}He,t)^{27}Si reactions for the excitation energy regions around 7.0 and 9.5 MeV, where the strongly populated residual states were observed in the ^{26}Mg(p,π^-)^{27}Si reaction. The energies assigned to the peaks are uncertain to about ±20 keV.

Fig. 3 presents the ^{24}Mg(α,p)^{27}Al experimental differential cross sections for states of interest together with zero-range DWBA calculations for different L-transfers. The results for the $^{27}Al(^{3}He,t)^{27}Si$ reaction are shown in Fig. 4.

Two approaches were used to assign spins and parities to states of interest: comparisons of the angular distributions with Distorted Wave Born Approximation (DWBA) calculations, and empirical comparisons of the distributions with those for states of known spin and parity. We used the first method to assign spins and parities to states formed in the $^{24}Mg(\alpha,p)^{27}Al$ reaction, since no suitable empirical angular distributions could be found, while the second method was applied to the $^{27}Al(^{3}He,t)^{27}Si$ reaction.

Zero-range DWBA calculations for the $^{24}Mg(\alpha,p)^{27}Al$ reaction at 48.2 MeV bombarding energy were carried out

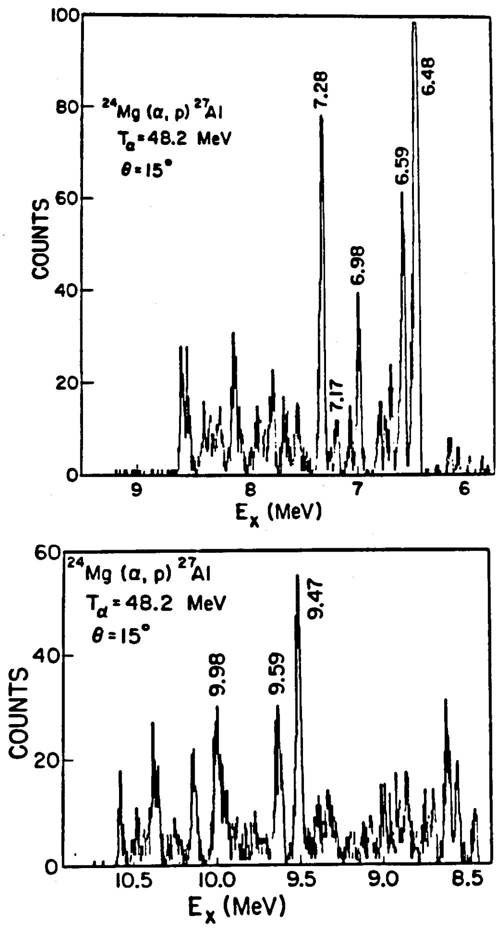

Figure 1. Spectra from the $^{24}Mg(\alpha,p)^{27}Al$ reaction at T_α = 48.2 MeV and θ_p = 15° in two excitation energy regions: 6.0 - 8.5 MeV (a) and 8.5 - 10.5 MeV (b).

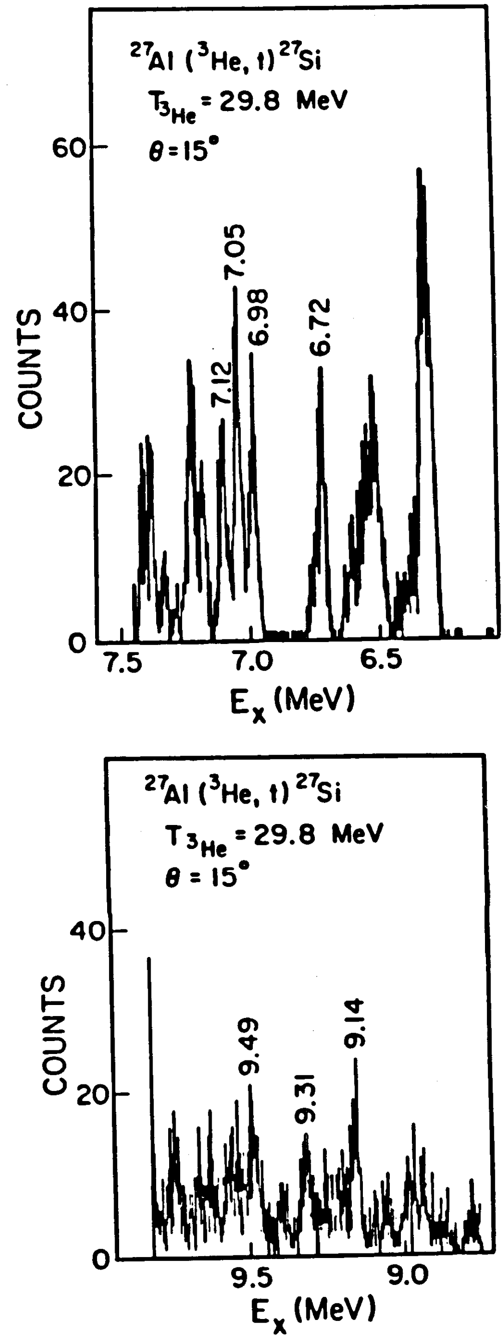

Figure 2. Spectra from the $^{27}Al(^{3}He,t)^{27}Si$ reaction at a bombarding energy of 29.8 MeV and the laboratory scattering angle of 15° in two excitation energy regions: 6.0 -7.5 MeV (a) and 8.5 -10.0 MeV (b).

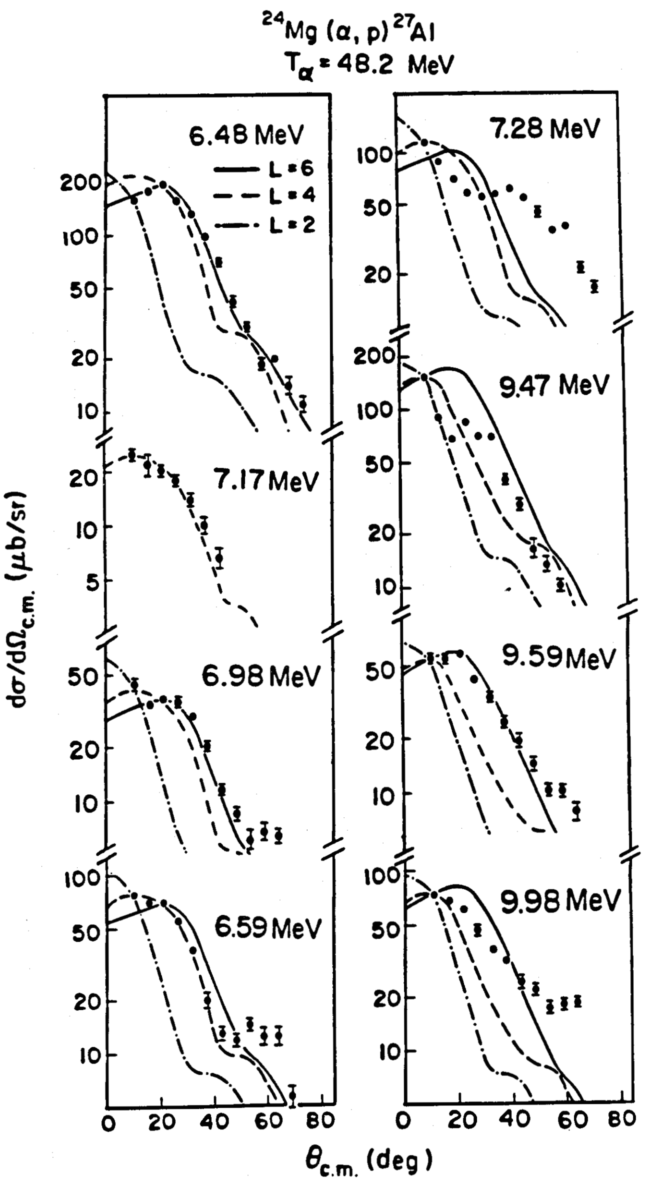

Figure 3. Cross section angular distributions for the peaks strongly populated around excitation energies of 7.0 and 9.5 MeV in the $^{24}Mg(\alpha,p)^{27}Al$ reaction at a bombarding energy of 48.2 MeV. The curves are from zero-range DWBA calculations assuming cluster orbital angular momentum transfers L = 2, 4, and 6.

using the computer code DWUCK4[5]. A cluster (triton) transfer to the sd-shell was assumed to form the same stretched state as that seen in the (p,π^-) reaction. According to this assumption, the possible angular momentum transfers in this reaction are L = 0, 2, 4, or 6. We are interested particularly in the L = 6 transition, since a high-spin $(13/2^+)$ state requires this L-transfer. The depth of the bound state well was adjusted to fit the cluster (triton) binding energy in the residual ^{27}Al nucleus, and the geometry parameters (radius and diffuseness) are those for a triton in ^{24}Mg at the appropriate energy.

The parameters of the optical potential were taken from Ref. 6, namely:

V = 100 MeV, r_o = 1.47 fm, a_o = 0.58 fm;

W_V = 27.6 MeV, r_w = 1.6 fm, a_w = 0.47 fm;

and r_c = 1.3 fm, for the entrance channel;

and

V = 39.7 MeV, r_o = 1.18 fm, a_o = 0.7 fm,

W_V = 7.04 MeV, r_w = 1.4 fm, a_w = 0.7 fm,

V_{so} = 7.5 MeV, r_{so} = 1.18 fm, a_{so} = 0.7 fm,

and r_c = 1.2 fm, for the exit channel.

The shapes of the angular distributions obtained from the DWBA calculations with L = 2, 4, and 6 shown in Fig. 3 are distinctively different from each other and are determined mainly by the L-value, so the DWBA calculations can be used to assign spins to the states of interest in ^{27}Al.

Satisfactory fits to the cross section angular distributions for the known[7] 6.48 MeV $(11/2^+)$ and 7.17 MeV $(9/2^+)$ states in ^{27}Al were achieved with L = 6 and L = 4, respectively. An L = 6 transition can form a final state of $11/2^+$, while L = 4 leads to a $9/2^+$ final state. The same optical model parameters therefore can be used with some confidence for the other strongly excited peaks around 7.0 and 9.5 MeV excitation energies.

We see in Fig. 3 that DWBA calculations with L = 6 reproduce the 6.98 and 9.59 MeV cross section angular distributions quite well. Thus, the 6.98 and 9.59 MeV states can be considered candidates for a $13/2^+$ spin and parity assignment.

The $(^3He,t)$ reaction can be used for spin determinations because of the distinctive shapes of the

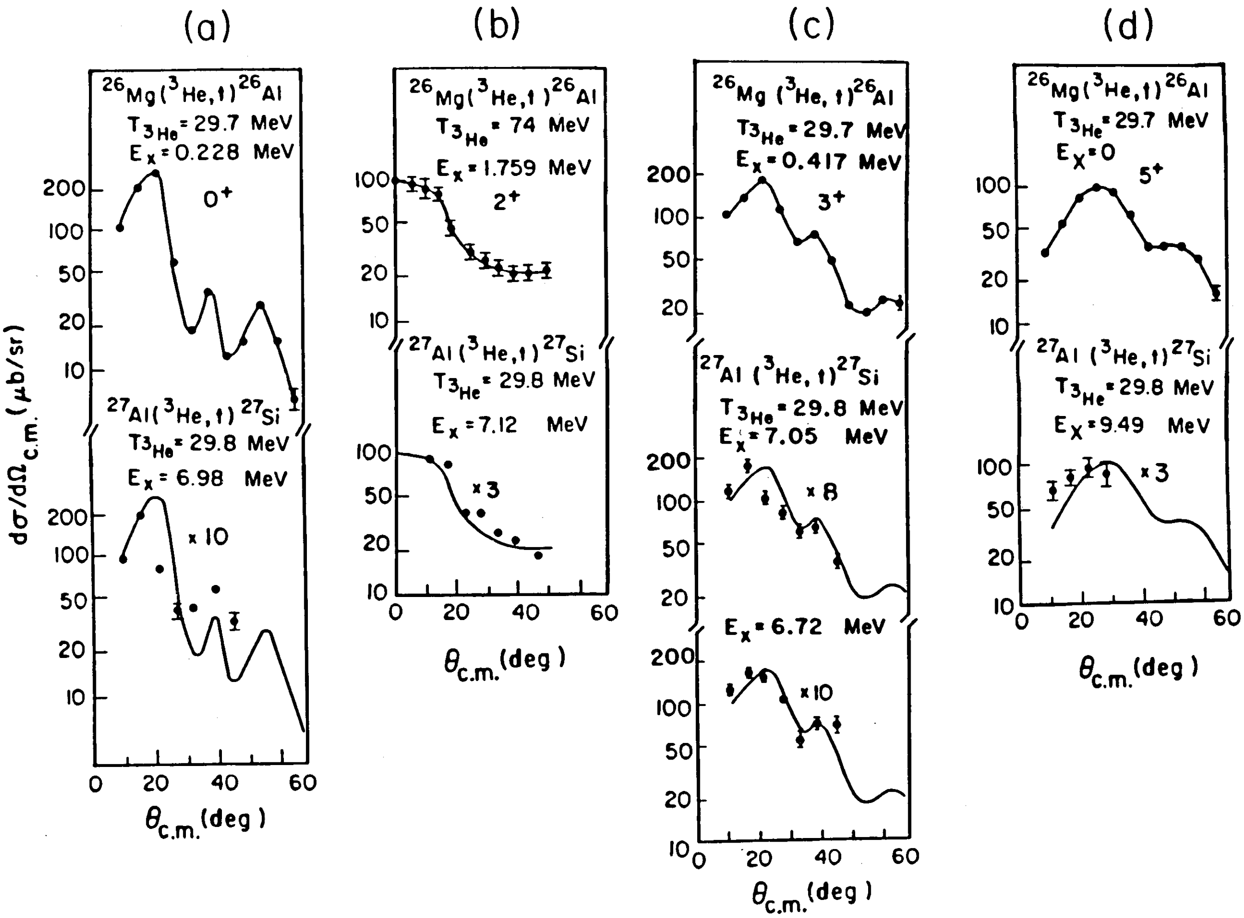

Figure 4. Comparisons of the observed (^{3}He,t) angular distribution for states of ^{27}Si around excitation energies of 7.0 and 9.5 MeV (bottom) with those for known states of J^π = 0^+, 2^+, 3^+, and 5^+ in ^{26}Al (top). The curves are the angular distributions of the prototypes shown at the top. The data points for ^{27}Si have been multiplied by the factors indicated in the figure.

angular distributions for transitions to states of different J and the striking stability of the shapes for transitions to states of the same J in a variety of nuclei over a wide range of bombarding energies.[8-10]

Angular distributions of the differential cross sections for transitions to the 0^+ (0.228 MeV), 3^+ (0.417 MeV), and 5^+ (0.0 MeV) final states in the ^{26}Mg(^{3}He,t)^{26}Al reaction obtained at 29.7 MeV bombarding energy in the present work are shown at the top of Figs. 4(a), (c) and (d), respectively. The angular distribution for the transition to the 2^+ (1.759 MeV) state obtained[11] at 74.0 MeV bombarding energy is shown at the top of Fig. 4(b). These transitions to final states of known J are used for empirical calibration of the shape "signatures" for L = 0, 2, 2+4, and 4 transitions. The 5^+ state is reached by an L=4 transition if only nucleons from sd-shell orbitals are involved in the reaction. We are interested in this transition because the high spin ($13/2^+$) state in ^{27}Si populated in the ^{27}Al(^{3}He,t)^{27}Si reaction requires an L = 4 transition.

Empirical spin and parity determinations for states of interest around 7.0 and 9.5 MeV excitation energies were made through the use of Fig. 4. The states are grouped according to the similarities of their angular distributions to those for transitions to the known lowest 0^+, 2^+, 3^+, and 5^+ states of ^{26}Al in the ^{26}Mg(^{3}He,t)^{26}Al reaction, shown at the top of each figure. Smooth curves drawn through these "prototype" angular distributions are superimposed on the data for the states of unknown spin at the bottom of Fig. 4.

We find no evidence from the ^{27}A(^{3}He,t)^{27}Si reaction for a high-spin ($13/2^+$) state in ^{27}Si near 7.0 MeV excitation energy. The angular distribution for the 9.49 MeV state of ^{27}Si is the only one that is similar to that for the ground state (5^+) of ^{26}Al. Hence, the 9.49 MeV state is the only candidate for a possible $13/2^+$ spin and parity assignment. However, since only forward angle data were taken for this state, the evidence for this assignment is weak. The high level density in this region of excitation energy together with the absence of any selectivity of the (^{3}He,t) reaction for high-spin states (because of the relatively low momentum transfer) make it difficult to pick out the high-spin states of interest using the (^{3}He,t) reaction.

A high spin ($13/2^+$) assignment for the 9.49 MeV state in ^{27}Si agrees with the result of the DWBA calculation for the analogue 9.59 MeV state in ^{27}Al and is also supported by ^{27}Al(^{3}He,t)^{27}Si data[12] taken at a bombarding energy of 65.0 MeV at the Indiana University Cyclotron Facility. Spectra from that experiment are shown in Fig. 5. The peak at Ex = 9.5 MeV is the only one with a larger yield at 20° than at 12°. It has been shown[11] for the ^{26}Mg(^{3}He,t)^{26}Al reaction at 74 MeV bombarding energy, that peaking of the differential cross section near 20° is a unique signature of a $J^\pi = 5^+$ transition to a high-spin state.

In summary, to provide supporting evidence for the high-spin ($13/2^+$) assignments to the 7.0 and 9.5 MeV states in ^{27}Si inferred from studies[2] of the ^{26}Mg(p,π^-)^{27}Si reaction, we have measured angular distributions of the cross sections for the

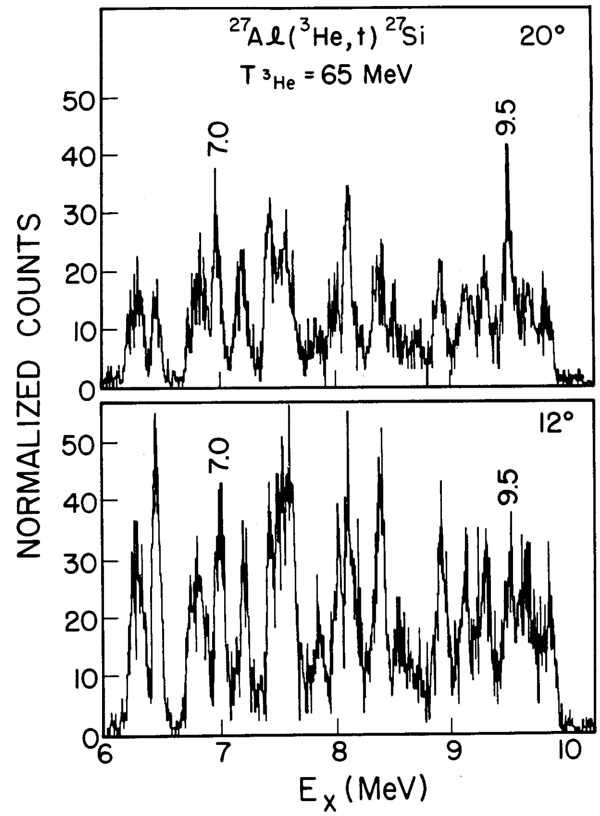

Figure 5. Spectra from the ^{27}Al(^{3}He,t)^{27}Si reaction in an energy region from 6.0 to 10.0 MeV at a bombarding energy of 65 MeV and two scattering angles of 20° (top) and 12° (bottom). The peak at Ex = 9.5 MeV is the only one with a larger yield at 20° than at 12°. This is a unique signature of a $J^\pi = 5^+$ transition to a high-spin state.

^{24}Mg(α,p)^{27}Al and ^{27}Al(^{3}He,t)^{27}Si reactions leading to states in ^{27}Al and ^{27}Si in the 7.0 and 9.5 MeV excitation energy regions. The (α,p) data provide evidence for two possible $13/2^+$ states in ^{27}Al at excitation energies of 6.98 and 9.59 MeV, while the (^{3}He,t) data give evidence for a possible $13/2^+$ state at 9.49 MeV in ^{27}Si. These results support the spin assignments inferred[2] from the ^{26}Mg(p,π^-)^{27}Si reaction studies and lend credence to applications[1] of the (p,π^-) reaction to other nuclei in the sd-shell to locate and identify high-spin two-particle one-hole states which are not readily observable by other reactions.

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