Evidence for Target-Excitation Effects in a Single-Particle-Transfer Reaction*

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The transitions to the $\frac{7}{2}^+$ and $\frac{9}{2}^+$ states in Mg^{25} have been measured with both the $Mg^{26}(He^3,\alpha)Mg^{25}$ and $Mg^{26}(d,t)Mg^{25}$ reactions. The only angular distribution that is fitted reasonably well by distorted-wave Born-approximation calculations is the $Mg^{26}(He^3,\alpha)Mg^{25}$ transition to the $\frac{7}{2}^+$ state. The larger cross section for the $\frac{7}{2}^+$ transition in the (He^3,α) reaction, and the differences between the shapes of the angular distributions of the transitions to the $\frac{7}{2}^+$ and $\frac{9}{2}^+$ states suggest strongly that the $\frac{7}{2}^+$ is excited primarily by a multiple-excitation process, while interference effects between the simple single-nucleon transfer and multiple excitation may be more important in the $\frac{9}{2}^+$.

THE extraction of spectroscopic factors for weak transitions in single-nucleon-transfer reactions is important to determine the presence of core excitation in nuclei. The uncertainty in these spectroscopic factors may, however, be quite considerable if an appreciable amount of target excitation occurs in the nucleon-transfer reaction. A number of experimental results[1–5] may require target-excitation effects. The effects of multiple excitations have been calculated theoretically by several authors.[6–10]

The excitation of the $\frac{7}{2}^+$ level in Mg^{25} has been interpreted[11] in the $Mg^{26}(He^3,\alpha)Mg^{25}$ reaction as due to single-particle pickup and as evidence for an appreciable amount of $1g_{7/2}$ admixture in the ground-state wave function of Mg^{26}.

Since both the $\frac{9}{2}^+$ and $\frac{7}{2}^+$ levels in Mg^{25} are well known as members of a rotational band, it appeared of interest to re-examine both the $Mg^{26}(d,t)Mg^{25}$ and $Mg^{26}(He^3,\alpha)Mg^{25}$ reactions to obtain an estimate for the single-particle strength. In the simple shell model, the fact that the $g_{9/2}$ shell is located well below the $g_{7/2}$ shell leads to the expectation that the $g_{7/2}$ admixture should be smaller than the $g_{9/2}$ admixture.

The experiment was performed with the 33-MeV He^3 beam and the 21.6-MeV deuteron beam of the Argonne 60-in. cyclotron. The particles were detected with a telescope of surface-barrier detectors. The experimental resolution width varied between 100 and 150 keV.

A typical α-particle spectrum is shown in Fig. 1. The $\frac{7}{2}^+$ level at 1.61 MeV is well resolved from known neighboring levels. However, the $\frac{9}{2}^+$ level at 3.399 MeV could not be resolved from the $\frac{3}{2}^-$ level at 3.408 MeV. The spectrum clearly shows that the $\frac{7}{2}^+$ level is more strongly excited than the combination of the $\frac{9}{2}^+$ and $\frac{3}{2}^-$ levels, in sharp contrast to the expectation from the simple shell model.

For each of the two reactions, Fig. 2 shows angular distributions of the transitions to the ground state, the 1.611-MeV state, and the unresolved doublet at 3.4 MeV, together with calculated curves which will be discussed below. In the (He^3,α) experiment, the distributions for the transitions to the $J^\pi=\frac{7}{2}^+$ state, and to the unresolved doublet have markedly different shapes. This difference is only partly due to the $l=1$ transition to the 3.408-MeV state, because this state is already rather weakly excited in the (d,t) reaction, and would be inhibited in the (He^3,α) reaction, in comparison with a transition involving high angular-momentum transfer. In any case, the $j^\pi=\frac{9}{2}^+$ state is on the average only $\frac{1}{2}$–$\frac{1}{3}$

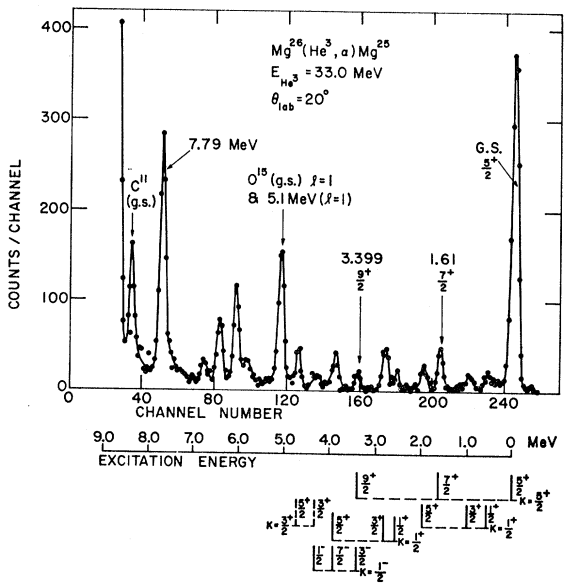

FIG. 1. Spectrum of α-particle energies.

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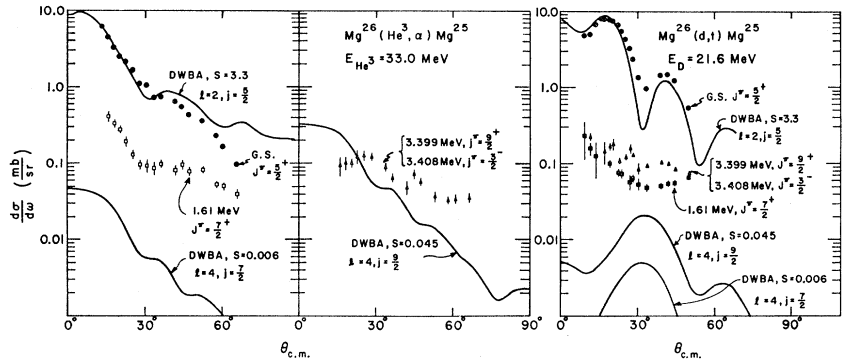

FIG. 2. Experimental and calculated differential cross sections.

as strongly excited as the $j^\pi=\frac{7}{2}^+$ state, and the angular distributions show different shapes.

To estimate the relative strength of $g_{9/2}$ and $g_{7/2}$ admixtures in the ground state of Mg^{26}, the wave functions of a neutron moving in a deformed Woods-Saxon potential in Nilsson orbit No. 5 have been calculated with a computer code written by Rost.[12] While the absolute spectroscopic factors for the transitions to the $\frac{9}{2}^+$ and $\frac{7}{2}^+$ states varied considerably with the chosen well parameters, the $g_{9/2}$ strength was found to be consistently almost an order of magnitude larger than the $g_{7/2}$ strength, thus confirming the assumption based on the shell model.

The bound-state wave functions obtained in these calculations have been used as the form factor in a distorted-wave Born-approximation (DWBA) calculation, which was performed with the code JULIE.[13] Optical-model parameters,[14–16] together with the well parameters used in the deformed Wood-Saxon calculations, are listed in Table I. Spin-orbit interaction was included in the He^3, d, and t channels by simply adding a spin-orbit potential of well-depth $V_{so}=8$ MeV to the optical-model potential. The result of the calculations is shown (curves) in Fig. 2. The DWBA curves were normalized to the experimental angular distributions of the ground-state transitions at forward angles.

The shape of the experimental $l=2$ angular distributions is reasonably well reproduced in both reactions. When the normalization constant for the (d,t) reaction is taken[17] to be $N=3.33$, the absolute spectroscopic factor for the ground-state transition is found to be $S=3.3$.

The shapes of the two $l=4$ angular distributions of the (d,t) reaction are very similar to those measured at $E_d=14.8$ MeV.[18] They bear no resemblance to the calculated curves. The $j=\frac{7}{2}^+$ (He^3,α) angular distribution is the only one whose shape is reasonably well fitted by the calculated curve. The experimental cross section would give a $1g_{7/2}$ single-particle strength of about 0.09 when the ground-state strength is taken to be $S=3.3$. It is clear that the strength of the transition to the $\frac{9}{2}^+$ state is considerably smaller if it is assumed to be due to $1g_{9/2}$ transfer.[19]

In addition to the drastic difference between the angular distributions of the $\frac{9}{2}^+$ and $\frac{7}{2}^+$ states, one apparently has a $\frac{7}{2}^+$ cross section which is at least an order of magnitude larger than might be expected from

TABLE I. Optical-model parameters.

Channel	E_{lab} (MeV)	V_0 (MeV)	W (MeV)	W_D[a] (MeV)	r_0 (F)	r_c (F)	a_0 (F)	r_i (F)	a_i (F)	V_{so} (MeV)	
$Mg^{26}+d$	21.6	61.2	···	17.40	1.416	0.571	0.571	1.088	0.847	8.0	Ref. 15
$Mg^{25}+t$	17.0	172.6	33.5	···	1.4	1.4	0.603	1.4	0.603	8.0	Ref. 16
$Mg^{26}+He^3$	33.0	167.1	20.5	···	1.1	1.4	0.688	1.688	0.75	8.0	Ref. 14
$Mg^{25}+\alpha$	40.4	84.7	12.92	···	1.52	1.52	0.606	1.80	0.538	···	Ref. 14
$Mg^{25}+n$	···	≈57.0[b]	···	···	1.25	1.25	0.65	···	···	7.9	

[a] W_D as defined in Ref. 15.
[b] Well depth adjusted to reproduce the binding energy $E_B=11.09$ MeV $+E_x$ with deformation parameter $\beta=0.35$.

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a comparison with the $\frac{9}{2}^+$ cross section. In addition to this, the $\frac{7}{2}^+$ cross section gives a $1g_{7/2}$ strength that is more than an order of magnitude larger than would be expected from the theoretical considerations.

Iano[10] has investigated the possibility of a multiple process, such as quadrupole excitation, and $d_{5/2}$ neutron transfer in the case of the $Mg^{24}(d,p)Mg^{25}$ reaction. From the dissimilarity of the distributions from the transitions to the $\frac{9}{2}^+$ and $\frac{7}{2}^+$ states, it is evident that such a calculation for the $Mg^{26}(He^3,\alpha)Mg^{25}$ reaction has to take account of interference effects between the single-particle direct reaction and the multiple process in at least one of the two transitions. In spite of the rather acceptable fit to the angular distribution, it seems clear that the excitation of the $\frac{7}{2}^+$ level cannot be due to a reaction involving direct single-neutron transfer only. Therefore considerable restraint may have to be used in the extraction of spectroscopic factors from weaker pickup transitions.

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Decay of In^{115m}†

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In addition to the previously reported isomeric transition (336.25±0.10 keV), a gamma-ray transition of (497.3±0.5) keV is observed in the decay of In^{115m}. From previous information, it is inferred that the latter transition represents an 0.06% beta-decay branch to the first excited state in Sn^{115}. The presence of this beta transition is consistent with the spin assignment of $\frac{3}{2}^+$ for this level.

PREVIOUS studies[1] of the decay of In^{115m} (4.5 h) have indicated only the presence of an isomeric gamma-ray transition of 336 keV. In the present study, a 497-keV transition has also been observed. This indicates the existence of a beta-decay branch to an excited state in Sn^{115}.

For this study, a sample of Cd^{115} was produced by neutron irradiation of normal cadmium. After allowing the sample to decay for one day, the indium was removed by several coprecipitations on $Fe(OH)_3$ with ammonia. After 2 h, the In^{115m} was milked from the Cd by another $Fe(OH)_3$ precipitation. This In was purified by repeated $Fe(OH)_3$ coprecipitations, by solvent extraction of $InBr_3$ with diethyl ether, and by selective elution from anion resin using HCl.[2]

Two gamma-ray spectra for In^{115m} are shown in Figs. 1 and 2. These clearly indicate the presence of a gamma ray at 497 keV. From successive spectra, it was shown that both gamma rays have the same half-life. In order to determine the gamma-ray energies, a spectrum of In^{115m}, Hg^{203}, and Au^{198} was measured using a Ge(Li) detector system. The resulting energies were 336.25±0.10 keV and 497.3±0.5 keV with relative

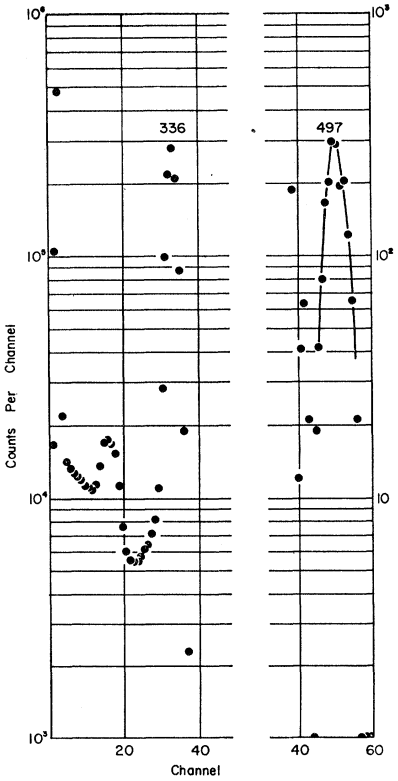

FIG. 1. Gamma-ray spectrum of In^{115m} measured on a 3-in.×3-in. NaI(Tl) detector with the source 10 cm from the detector.

† Work performed under the auspices of the U. S. Atomic Energy Commission.

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