Stretched states in ^{26}Mg from the ^{25}Mg(α,^{3}He) reaction at 81 MeV

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(Received 4 August 1986)

The ^{25}Mg(α, ^{3}He)^{26}Mg reaction was used at 80.9 MeV to investigate the stretched 6^- states from the $(d_{5/2}^{-1},f_{7/2})$ particle-hole configuration, which had been identified by inelastic electron scattering. The summed spectroscopic factors for the $T=1$ 6^- states are only about 27% of the expected strength and are to be compared to 85% of the extreme single model strength found in inelastic electron scattering. The $T=1$ 6^- spectroscopic strength is considerably more fragmented in the mass 26 system than it is in mass 28.

I. INTRODUCTION

The states of maximum angular momentum found from the $(d_{5/2}^{-1},f_{7/2})_{6^-}$ particle-hole configuration have been the subject of several recent investigations in the mass 28 and 26 systems. The interest in these stretched 6^- states, which are thought to be rather pure particle-hole states, stems from the role that collective nuclear structure effects could have on the damping and splitting of the single-particle aspects. For this reason it is important to study the excitation of these single-particle states both by inelastic scattering and by explicit single-nucleon stripping, since the strengths for the two classes of reactions are differently influenced by many of the causes hypothesized for this damping and splitting.

While stretched 6^- states in the mass 28 system have been rather completely examined,[1-7] the mass 26 system has been less so, due basically to the lack of nucleon transfer data to the appropriate 6^- states in ^{26}Mg. It is the purpose of the present experiment to determine spectroscopic factors for the population of the known $T=1$ 6^- states by the ^{25}Mg(α,^{3}He)^{26}Mg reaction. Information on the 6^- states in ^{26}Mg has come primarily from inelastic electron scattering[8,9] and inelastic proton scattering.[10]

A study[11] similar in intent to the present one was carried out using the ^{25}Mg(α,t)^{26}Al reaction, also at 80.9 MeV, to the $T=0$ and $T=1$ stretched 6^- states. The present work examines the $T=1$ analog levels in ^{26}Mg; the $T=2$ states of ^{26}Mg known from inelastic scattering cannot be accessed by single-nucleon stripping.

The (α,t) reaction, and also, of course, the (α,^{3}He) reaction, will tend preferentially to populate states that involve $f_{7/2}$ stripping because of the large angular momentum mismatch. The (α,t) study identified five $T=1$ 6^- states in ^{26}Al mainly by comparison with $T=1$ 6^- analogs in ^{26}Mg that had been previously located.[8-10] The advantages of the (α,^{3}He) reaction are that less complicated spectra can be expected since the many $T=0$ levels in ^{26}Al will not be present in ^{26}Mg and the identification of the 6^- states should be more direct than relying upon the analogs in ^{26}Al.

II. EXPERIMENTAL PROCEDURE

The experiment was carried out with a beam of 80.9 MeV alpha particles from the AVF cyclotron at the Research Center for Nuclear Physics at Osaka University. The ^{3}He ions from the ^{25}Mg(α,^{3}He)^{26}Mg reaction were momentum analyzed using the magnetic spectrograph RAIDEN.[12] The detector[13] consisted of a position-sensitive proportional counter 1.5 m in length, two gas proportional counters that furnished ΔE signals, and a stopping plastic scintillation counter that furnished an E signal. The final momenta spectra were obtained in an off-line analysis where particle identification was obtained by two-dimensional gates being set in the ΔE-E spectra.

The targets were self-supporting metallic foils of ^{25}Mg and ^{24}Mg with measured thicknesses of 0.44 and 0.45 mg/cm^2 and enrichments of 97.87% and 99.94%, respectively. Data were taken on the ^{25}Mg(α,^{3}He) reaction over the angular range 5°–50° with four separate settings of the spectrograph magnetic field to cover the excitation region up to to 18 MeV in ^{26}Mg. Data were also taken on the ^{24}Mg(α,^{3}He)^{25}Mg reaction over a similar angular range with one setting of the magnetic spectrograph in order to obtain angular distributions for known $l=3$ transitions to the states at 3.97 and 7.28 MeV in ^{25}Mg. For a

check on the normalization of the $(\alpha,^3\text{He})$ cross sections, elastic alpha particle scattering cross sections were measured for both the ^{24}Mg and ^{25}Mg targets at eight angles between 4.6° and 27.8°. A comparison was made between the measured elastic cross sections and the predicted cross sections using the optical model parameters employed in an earlier study[7] of the ^{27}Al$(\alpha,t)^{28}$Si and ^{27}Al$(\alpha,^3\text{He})^{28}$Al reactions at MeV. Using the quoted target thicknesses and the nominal solid angle of the spectrometer of 3.2 msr, agreement was obtained with the predicted cross sections well within ±10%. The uncertainty in the overall normalization of the cross sections is thus estimated to be 10% or less.

At scattering angles less than 10° it was necessary to reduce the solid angle of the spectrometer to 1.0 msr in order to avoid having the Faraday cup partially block the entrance to the spectrometer. Data were taken at laboratory angles of 5, 7.5, and 10° with this smaller solid angle and also with a smaller Faraday cup. Because incomplete charge collection was experienced with the smaller Faraday cup, it was necessary to renormalize the small angle data by a factor of 1.20 in order to be consistent with the 10° data taken with the large Faraday cup.

In order to evaluate the effects of small amounts of carbon and oxygen on the magnesium targets, data were also taken at a number of angles and excitation energies with a Mylar target that was 4.6 μm thick. A composite spectrum is shown in Fig. 1 for the ^{25}Mg$(\alpha,^3\text{He})^{26}$Mg reaction at a laboratory scattering angle of 10°. The energy resolution at the smaller angles was about 32 keV, but this deteriorated some at the larger angles.

The area and location of each peak was determined by using the peak fitting program SPECFIT (Ref. 14) with a linear background assumption. The excitation energies were determined by calibration of the focal plane with the known energies[15] of the states in ^{26}Mg up to about 7.0 MeV. The energies of some of the states that are more strongly populated are shown in Fig. 1. The accuracy of the energy determination is estimated to be better than 5 keV up to 10 MeV and 10 keV between 10 and 17 MeV.

III. DISTORTED WAVE CALCULATIONS

Distorted wave Born approximation (DWBA) calculations were carried out in order to obtain spectroscopic factors for the $(\alpha,^3\text{He})$ reaction to the various states of interest in ^{26}Mg and to some extent help in identifying the shape of the angular distributions with a particular l value. For this purpose both zero-range[16] (DWUCK4) and exact-finite-range[16] (DWUCK5) and (TWOFNR) (Ref. 17) DWBA programs were utilized. The optical model parameters for both the incident α particles and the outgoing ^{3}He particles were taken directly from Ref. 7, which was a study of the stretched 6^- states in ^{28}Si and ^{28}Al via the (α,t) and $(\alpha,^3\text{He})$ reactions at 80 MeV. These same parameters were used in the recently reported ^{25}Mg$(\alpha,t)^{26}$Al study.[11] The optical model parameters were of a deep-well type for the α particles and a shallow-well type for the ^{3}He particle.

There are several major uncertainties associated with the application of the DWBA for the extraction of spectroscopic factors for the reaction of interest. The detailed choice of the geometrical parameters for the neutron bound state calculation can affect the overall magnitude of the DWBA cross sections and to some extent the shape of the angular distribution. A rather extensive discussion of the effect of variations of the radius parameter, r_0, and the diffuseness parameter, a, used in calculations with the Woods-Saxon potential for the bound proton was presented in Ref. 11. Bound state geometries based upon several

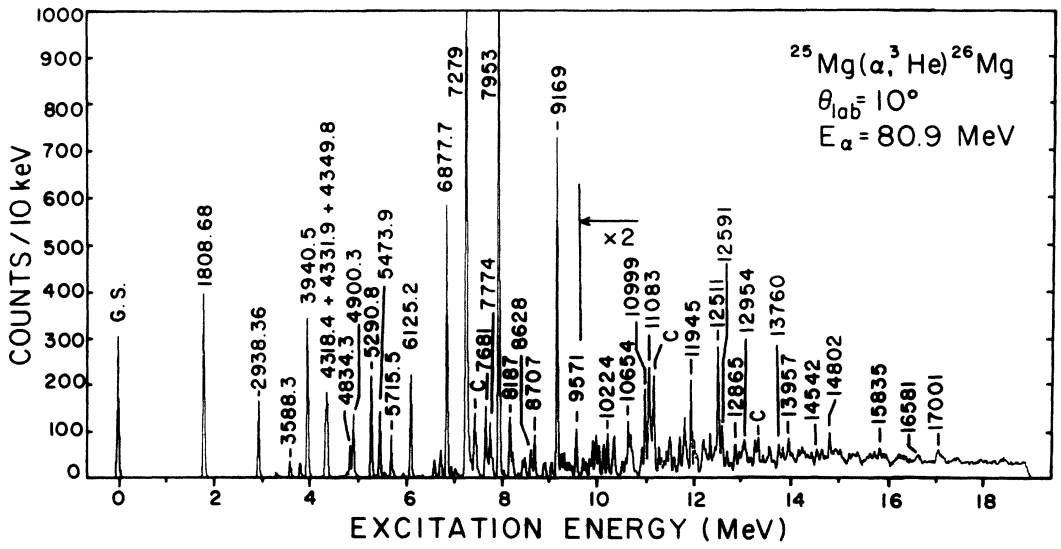

FIG. 1. A composite energy spectrum for the ^{25}Mg$(\alpha,^3\text{He})^{26}$Mg reaction at a laboratory scattering angle of 10°. The energies of the levels in ^{26}Mg are shown in keV above the ^{3}He peaks. The energies for the levels up to 6877.7 keV were taken directly from Ref. 15 and those at higher energies are from the present study. The peaks marked with a C are due to carbon on the target. The scale for the region above 9571 keV is twice that shown on the left of the figure.

reasonable schemes when used in a zero-range distorted wave calculation produced differences in cross section up to about 30% higher and 30% lower than those obtained when the adopted parameters were used. In order to facilitate comparison of the present work with the results of the (α,t) study,[11] as well as the earlier work on the (α,t) and $(\alpha,{}^3He)$ reactions to ^{28}Si and ^{28}Al, the value r_0 has been taken as 1.25 fm, a as 0.65 fm, and λ, the spin-orbit coupling constant, as 25 times the Thomas term. These values have also been used for a recent reinterpretation of the electron scattering data to the 6^- states of ^{26}Mg.[18]

The states up to 7.33 MeV in ^{25}Mg and 11.09 MeV in ^{26}Mg are bound against neutron emission. Because of the interest in states up to 16.5 MeV in ^{26}Mg, the problem of the use of unbound form factors in the DWBA calculations must be considered.

The zero-range program[16] DWUCK4, which uses the method of Vincent and Fortune[9] for treating these unbound states, was utilized for this purpose since the available DWUCK5 (Ref. 16) and TWOFNR (Ref. 17) exact-finite range programs did not have this feature. Comparisons were made between the exact-finite-range and zero-range calculations for the two test states in ^{25}Mg that are both bound and for the 9.18 and 14.542 MeV states in ^{26}Mg, the latter of which is unbound. The zero range calculations were carried out using a normalization parameter, $D_0=275$ MeV fm$^{3/2}$, a finite range parameter of 0.7 fm, and nonlocal parameters of 0.85, 0.25, and 0.20 fm for the neutron, ^3He, and alpha particle, respectively. For both the zero-range and exact-finite range calculations the light particle spectroscopic factor s was set equal to 2. The isospin coefficient C^2 is equal to 1 for the $(\alpha,{}^3He)$ reaction to both ^{25}Mg and ^{26}Mg.

The exact-finite-range calculations were carried out for the states of interest in ^{26}Mg using the DWUCK5 program, which allows for the inclusion of a nonlocal correction factor for the neutron, ^3He, and alpha particle. These were set equal to the same values used in the zero-range calculations. Calculations to unbound states were done by treating them as bound by 0.1 MeV. The light particle form factor that was used was the same used in the $(^3He,\alpha)$ studies[20] and was represented in momentum coordinates out to $q=15$ fm^{-1}.

As a check on the ability of the distorted wave calculations to predict the correct shape for well established $l=3$ transitions, data were taken on the 3.97 and 7.28 MeV states in ^{25}Mg. These states are both thought[15] to have a spin and parity of $\frac{7}{2}^-$. The measured cross sections are shown in Fig. 2 with the results of both zero-range (DWUCK4) and finite-range (DWUCK5) calculations. The shapes of the experimental angular distributions are reasonably well accounted for by both sets of calculations, except for the tendency to overpredict the data at the larger angles, although it also appears that the zero-range calculations come somewhat closer to the data at these larger angles. The spectroscopic factors obtained for the two types of calculations for the two states are shown in Table I. It can be seen that the results from these two calculations for the present experimental results are in good

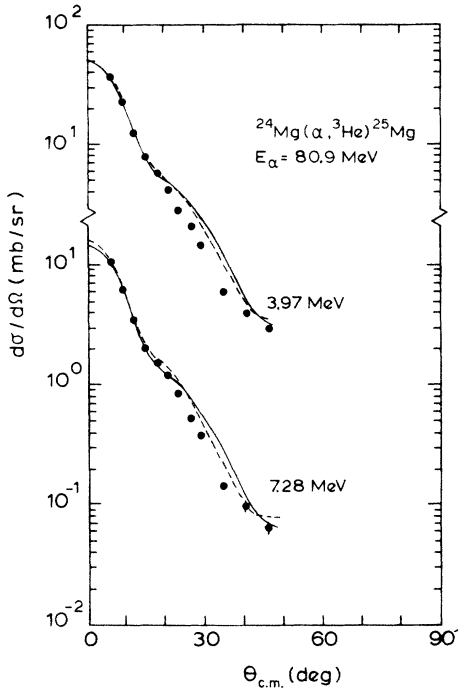

FIG. 2. Angular distributions for the 3.97 and 7.28 MeV states in ^{25}Mg, both of which are known to have a spin and parity of $\frac{7}{2}^-$. The dashed and solid lines shown are the results of zero-range and exact-finite-range distorted wave calculations, respectively.

TABLE I. The spectroscopic factors S obtained with the zero-range (ZR) and exact-finite-range (EFR) calculations for the 3.97 and 7.28 MeV states in ^{25}Mg.

		Spectroscopic factors			
		Present work		Literature	
^{25}Mg	J_f^π	ZR	EFR	(d,p)[a]	$(\alpha,{}^3He)$[b]
E_x (MeV)					
3.97	$\frac{7}{2}^-$	0.22	0.23	0.43	0.60
7.28	$\frac{5}{2}^-,\frac{7}{2}^-$	0.10[c]	0.10[c]		0.44

[a]Reference 21.
[b]Reference 22.
[c]A spin of $\frac{7}{2}^-$ has been assumed.

TABLE II. Spectroscopic factors from the present experiment and related experiments for the stretched $T=1$ 6^- states in ^{26}Mg and ^{26}Al, as computed with DWUCK.

^{25}Mg$(\alpha,{}^3$He)			^{26}Mg(p,p')[a]	^{26}Mg(e,e')				^{25}Mg$(\alpha$,t$)^{26}$Al[d]	
E_x (MeV)	S_{DW4}	S_{DW5}	E_x (MeV)	E_x	T	% ESPM[b]	% ESPM[c]	E_x (MeV)	S_{DW5}
				7.45±0.02	1	0.8±0.2	0.9		
9.169	0.123	0.130	9.18±0.03	9.17±0.01	1	6.2±0.2	6.9	9.264±0.005	0.20
11.945	0.031	0.029	11.98±0.03					11.969±0.005	0.080
12.512	0.063	0.056	12.48±0.03	12.50±0.04	1	8.2±0.2	10.7	12.404±0.005	0.065
12.865	0.015	0.013	12.85±0.03	12.88±0.05	1	3.6±0.2	4.9	12.547±0.005	0.058
12.958	0.006	0.005		13.00±0.005	1	2.5±0.2	3.4		
13.958	0.020	0.017		13.97±0.03	1	3.3±0.2	4.8		
14.542	0.014[e]	0.012		14.50±0.05	1	4.5±0.2	7.9		
				15.36±0.04	1	4.9±0.4	9.0		
16.58	0.009[e]	0.009		16.5	1	12.2±0.7	20.1		
			18.05±0.05	18.05±0.07	2	39 ±1.7	83		
$\sum S(6^-;1)$	=0.281	=0.271				$\sum(6^-;1)=55.2$	85.4	$\sum S(6^-;1)$	= 0.40

[a]Reference 10.
[b]Reference 8.
[c]Reference 18.
[d]Reference 11.
[e]Values obtained using a resonance form factor.

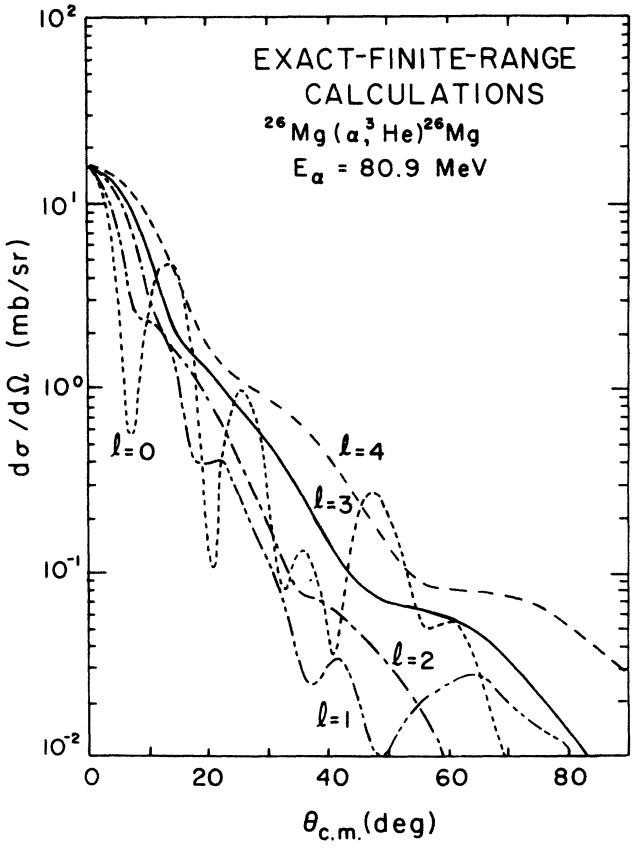

FIG. 3. Calculated angular distributions for l values of 0, 1, 2, 3, and 4 using the exact-finite-range distorted wave program TWOFNR. All of the angular distributions have been normalized to have the same cross section at 0°.

agreement with each other, but are considerably less than the (d,p) spectroscopic factors of Meurders and de Korte,[21] who use the same bound state parameters as in the present work. The spectroscopic factors of Yang and Singh[22] obtained from the $(\alpha,{}^3\mathrm{He})$ reaction at 70 MeV are also higher. These differences are not understood at the present time.

Because of the close agreement between the spectroscopic factors obtained using zero-range and exact-finite-range calculations both for the two states in ^{25}Mg and for the bound and unbound states in ^{26}Mg, as is seen in Tables I and II, no correction to the exact-finite-range spectroscopic factors appeared necessary for the unbound final states of interest.

In Fig. 3 are shown angular distributions calculated using TWOFNR for l values of 0, 1, 2, 3, and 4 for the transitions to the states at 9.18 MeV in ^{26}Mg. The different angular distributions have all been normalized at 0° in order to show the dependence of the slope in the differential cross section at small scattering angles to the l value. While one can rather readily distinguish l values of 0, 1, and 4 from $l=3$, it is, in practice, rather difficult to distinguish $l=2$ from 3 even though their initial slopes are somewhat different. For a given l value the slope of the calculated angular distributions changed very little over the range of excitation energies of interest, but the magnitude of the cross sections decreased by a factor of about 4 going from 9.18 to 16.50 MeV of excitation energy.

IV. THE STRETCHED 6^- STATES IN ^{26}Mg

The results of the electron[8] and proton[9] studies for the $T=1$ 6^- states in ^{26}Mg are shown in Table II. As can be seen in Fig. 1, a very large number of states were strongly excited by the ^{25}Mg$(\alpha,{}^3$He$)^{26}$Mg reaction. It was not pos-

sible to determine uniquely from the stripping data alone which of these many states had a spin and parity of 6^-. In view of the calculations shown in Fig. 3, one faces an ambiguity in l value between 2 or 3, and also in the assignment of the spin and parity, given that the target ground state has $J^\pi = \frac{5}{2}^+$. With these limitations it was only possible to assume that the states shown in Table II from the electron and proton scattering experiments were, in fact, 6^- and to use the $(\alpha, {}^3\mathrm{He})$ reaction to extract a spectroscopic factor, providing the angular distribution was consistent, the energy of the $(\alpha, {}^3\mathrm{He})$ state was correct within the determined uncertainty, and the width of the state was compatible with its bound or unbound nature.

The angular distributions for seven of the eight states that are thought to be 6^- are shown in Fig. 4. The data are well described by the $l = 3$ distorted wave calculations. There are only minor differences in shape between the zero-range and exact-finite-range calculations for the state at 9.169 MeV, but the differences are more significant for the unbound state at 14.542 MeV. The spectroscopic factors have been extracted for both types of calculations and are shown in Table II. The errors shown reflect the uncertainty in normalizing the calculations to the data. There is, in addition, an overall uncertainty[11] in the absolute values of the spectroscopic factors of about 30% related to the theoretical calculations and an uncertainty of 10% due to the normalization of all the data.

In addition to the seven states whose angular distributions are shown in Fig. 4, there was evidence of a weakly populated state at 16.58 MeV, with a width of about 100

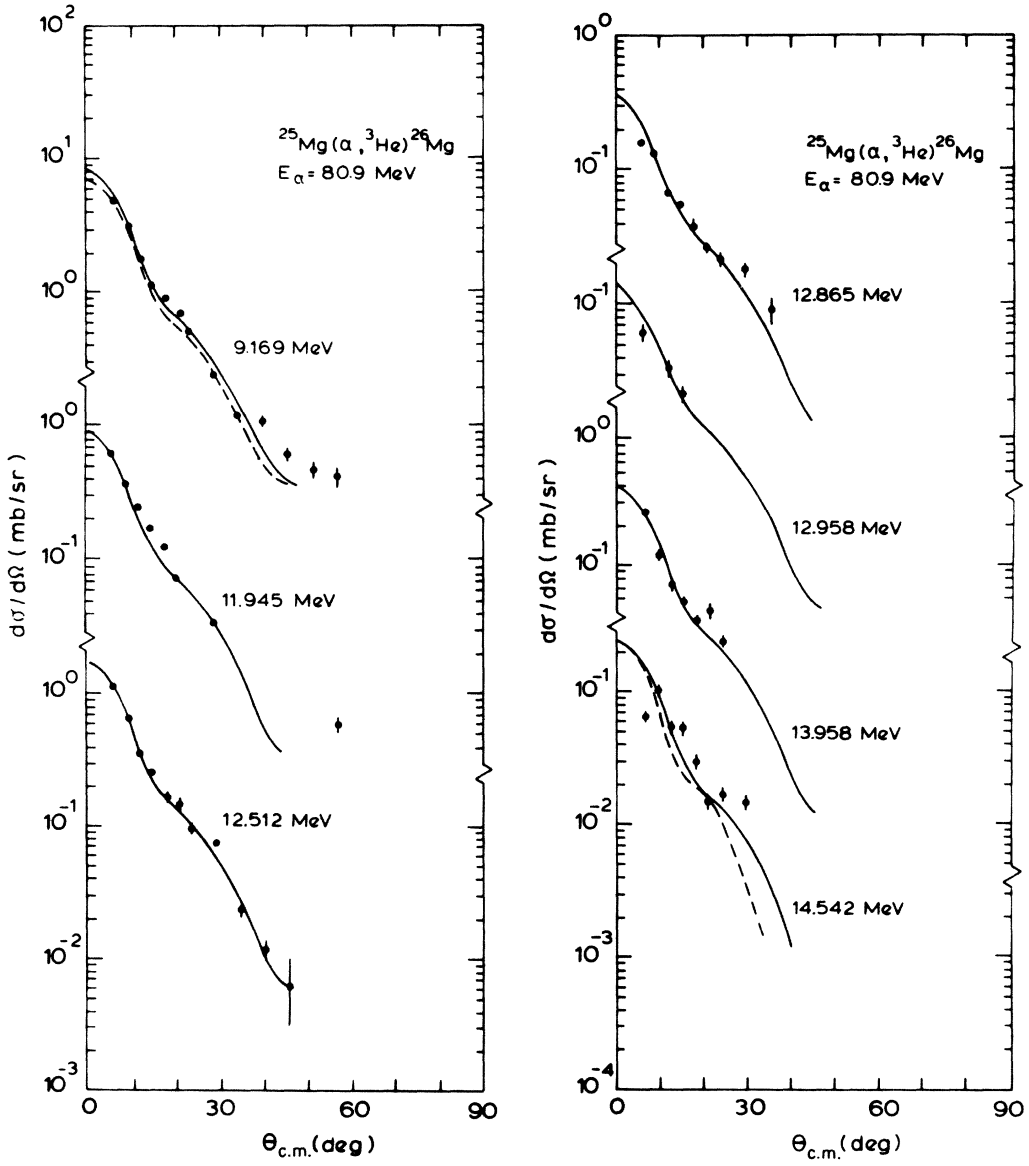

FIG. 4. The measured angular distributions for the states in ^{26}Mg that are thought to be the stretched 6^- states. The solid lines are the results of $l = 3$ exact-finite-range distorted wave calculations described in the text. The dashed lines for the states at 9.169 and 14.542 MeV are zero range calculations.

keV. This state was only in evidence at laboratory scattering angles of 5°, 7.5°, and 10°, but it could well be related to the complex containing a 6^- $T=1$ state found in electron scattering at 16.50 MeV.[8] There was no evidence in the $(\alpha,^3\text{He})$ reaction for population of the $T=1$ states at 15.30 and 15.46 MeV. As can be seen in Fig. 1, there were also no states seen around 18 MeV. Since the state at 18.05 MeV seen in the inelastic electron scattering has $T=2$, it should not be populated with the $(\alpha,^3\text{He})$ reaction.

With some exceptions, the results of the ^{25}Mg$(\alpha, t)^{26}$Al study of the $T=1$ 6^- states compare favorably with those of the present study to the mirror states. It is to be expected that the $(\alpha,^3\text{He})$ study will see more states than the (α,t) study since the energy resolution was considerably better (32 vs 80 keV) and the full excitation region up to 18 MeV was covered. The state at 7.54 MeV which was weakly populated in the inelastic electron scattering was not observed at all in the $(\alpha,^3\text{He})$ reaction. The state at 7.527 MeV seen in the (α,t) study was 6^- with $T=0$ and hence should not be present in ^{26}Mg. The states at 9.264, 11.969, 12.404, and 12.547 MeV seen in the (α,t) study[11] are presumably the analogs of the states at 9.169, 11.945, 12.512, and 12.865 MeV seen in the $(\alpha,^3\text{He})$ study. The analogs of the states at 12.958, 13.958, and 14.542 MeV were not seen in ^{26}Al since data were not obtained between excitation energies of 13 and 16 MeV. In the ^{25}Mg(α,t) study[11] a 6^- state was reported at 16.83 MeV in ^{26}Al. It is now believed[23] that this peak and several others noted in Ref. 11 were due to the ^{25}Mg$(\alpha,d)^{27}$Al g.s. reaction and that there is no appreciable proton transfer strength to states around 16 MeV and higher in ^{26}Al. Also, in a recent investigation[24] of the ^{25}Mg$(^3\text{He},d)^{26}$Al reaction no prominent peak was observed around 16.5 MeV.

The spectroscopic factors from the present experiment and the ^{25}Mg$(\alpha,t)^{26}$Al study are listed in Table II along with strengths from inelastic electron scattering,[8] in terms of the percentages of the isovector strength to $T=1$ states from the extreme single-particle model. The original strengths from the electron scattering were computed using harmonic oscillator potentials to generate bound nuclear wave functions.[8] A reanalysis of these data using wave functions for the same Woods-Saxon potential used for the stripping reactions gave the second column of isovector strengths.[18] The results in Table II are such that the sum would be 100% for the $T=1$ states alone in the single-particle limit. Another common presentation compares the data to the isovector strength summed for both $T=1$ and $T=2$ states. The spectroscopic factors from the neutron and proton stripping experiments are defined such that the total strength of the $T=1$ 6^- states should equal 1 if one was stripping into a completely empty shell.

There are some major differences between the spectroscopic factors from the neutron and proton transfer experiments, with the latter exhibiting nearly twice the $T=1$ summed spectroscopic factor. The distribution of strength between the various $T=1$ 6^- states is also somewhat different between the two experiments. One explanation of the difference in the distribution of the strength is the possibility of isospin mixing in ^{26}Al between the $T=0$ and $T=1$ 6^- states. The total sum of $T=1$ strength is 0.40 for ^{26}Al, whereas it is only 0.27 in ^{26}Mg. This difference in the summed strength for the two nuclei is not understood at the present time. The summed strength for the $(\alpha,^3\text{He})$ reaction is also considerably less than the total $T=1$ strength observed in the electron scattering (85%), based on the extreme single-particle model, using the Woods-Saxon potential.[18]

It is useful to examine more explicitly the ratio of the spectroscopic factors for the transitions to the states at 9.18 MeV in ^{26}Mg and 9.26 MeV in ^{26}Al, the lowest and strongest $T=1$ 6^- states in the mirror reactions, since it deviates substantially from the expected value of 1. The ratio of the DWUCK4 calculations at 0° is 0.575 for ^{26}Al/^{26}Mg. The same ratio of the experimental cross sections is 0.425. This yields a ratio of spectroscopic factors of 1.48 ± 0.20 when the fact that C^2, the isospin coefficient, is 0.5 for ^{26}Al and 1.0 for ^{26}Mg is taken into account. The indicated uncertainty is based on the independent experimental normalization uncertainties for the two experiments, although both were also found to agree with elastic scattering predictions.

Mirror symmetry would demand that the ratio of spectroscopic factors be unity, not 1.48. If the 9.26 MeV state of ^{26}Al were a single proton state, not a state of good isospin, C^2 would be unity and the ratio of spectroscopic factors becomes 2. A proton-like isospin mixed state

$$|9.26\rangle=\alpha\,|T=1\rangle-\beta\,|T=0\rangle\ ,$$

with $\alpha=0.969$ and $\beta=0.247$ yields an isospin coefficient $C^2=0.74$, which accounts for the breakdown of the expected mirror symmetry. In many lighter nuclei it has been noted that stretched states near particle thresholds often show single-particle features,[25] not being states of good isospin. Thus it is perhaps not surprising to note this effect in ^{26}Al as well. The present case is the first observed by nucleon transfer reactions.

The situation in ^{28}Si and ^{28}Al regarding the $(d_{5/2}^{-1},f_{7/2})$ particle-hole multiplet is somewhat different than the ^{26}Mg-^{26}Al case. In the former case the spectroscopic strength for the $T=1$ 4^-, 5^-, and 6^- states is largely localized in just three states, one for each spin. The spectroscopic factors for the (α,t) reaction to the $T=1$ 6^- state in ^{28}Si is 0.57 (Ref. 5) or 0.29 (Ref. 7) and is 0.35 (Ref. 5) or less for the $(\alpha,^3\text{He})$ reaction to the analog state in ^{28}Al, whereas values of about 0.6 are expected from shell model calculations.

Zamick[26] has investigated the effects of nuclear deformation on the single particle predictions for the stretched 6^- states in ^{28}Si. In particular, he showed that the effects of the $K=6^-$ band in ^{28}Si were to reduce both the spectroscopic strengths as well as the $M6$ strengths and to cause fragmentation of the $T=1$ 6^- strength. Under the deformed picture greater fragmentation of the inelastic excitation strength can be expected compared to that of the spectroscopic strength. It seems evident that the deformed model is playing an even greater role in mass 26 nuclei than it does in mass 28 nuclei, since the fragmentation is considerably greater. It is also interesting to note that for mass 26 the inelastic excitation is considerably more fragmented than is the spectroscopic strength for the $(\alpha,^3\text{He})$ reaction. The distribution of transition

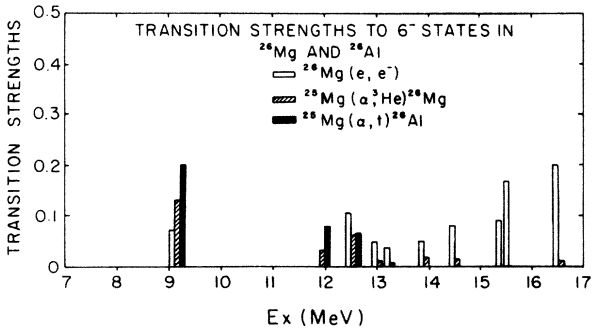

FIG. 5. The transition strengths to the 6^- states in ^{26}Mg and ^{26}Al. The strengths for both the inelastic electron scattering and nucleon transfer reactions are defined in such a way that the sum for the $T=1$ states should be 1.0 if the extreme single particle model was valid.

strengths is shown in Fig. 5 for the three reactions leading to the stretched 6^- states in ^{26}Al and ^{26}Mg. There is an inconsistency in the pattern displayed, since there is a lack of any (e,e') strength to a state around 12 MeV.

V. OTHER STATES IN ^{26}Mg

While the main purpose of this study is concerned with the stretched 6^- states in ^{26}Mg, there are several other states that have been observed that are of some interest. It is clear, in fact, from Fig. 1 that the states at 6877.7, 7278, and 7953 keV are equally or more excited at a scattering angle of 10° than is the state at 9169 keV that carries most of the 6^- strength. The angular distributions for these three states are shown in Fig. 6. The solid lines shown are the results of exact-finite-range distorted wave calculations for $f_{7/2}$ transfer.

The state at 6.878 MeV has been assigned[15] a spin and parity of 3^- and a recent study of the ^{25}Mg(d,p)^{26}Mg reaction at 13 MeV (Ref. 27) confirmed this assignment and obtained values of the spectroscopic factors for an $l=1$ and an $l=3$ component of the transition. For transitions to 3^- and 4^- states, it is possible to have an incoherent sum of $l=1(p_{3/2})$ and $l=3(f_{7/2})$ components. For 5^- and 6^- states only the $l=3$ transfer can contribute. The (d,p) reaction at low energies has a far greater l value dependence for the shapes of angular distributions than does the $(\alpha,^3\text{He})$ reaction at 80 MeV. For this reason the ratio of $l=3$ to $l=1$ spectroscopic factors was taken from the work of Arciszewski *et al.*[27] for the state at 6.878 MeV. The contribution of the $l=1$ transfer to the total calculated angular distribution is shown in Fig. 6 and the spectroscopic factors are listed in Table III along with the results of Arciszewski *et al.* It should be noted that again considerably smaller values of S are obtained from the present analysis.

The state at 7.278 MeV was unassigned in the compilation of Endt and van der Leun[15] and a doublet of states at 7.262 and 7.282 MeV was seen in the (d,p) study.[27] The angular distribution for the unresolved doublet in Fig. 6 appears to be predominantly $l=3$ and from the measured energy of 7.279 MeV the 7.282 MeV state must be the

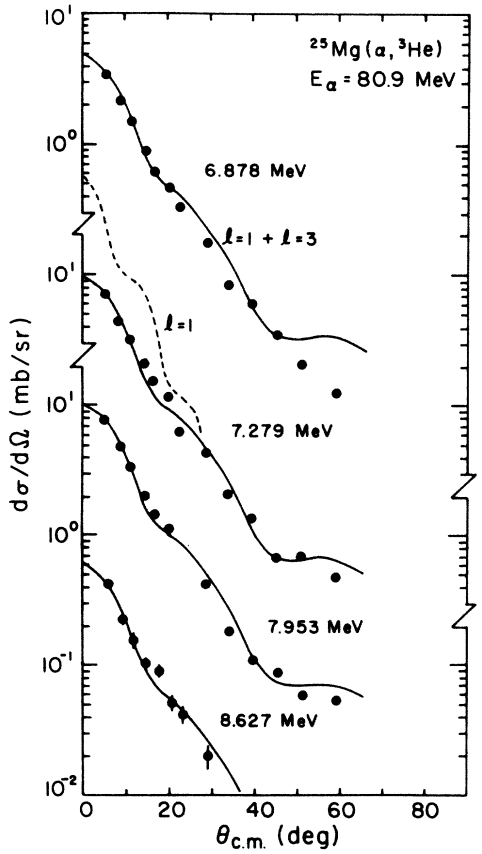

FIG. 6. The measured angular distributions for three very strong transitions to states at 6.878, 7.279, and 7.973 MeV in ^{26}Mg. The solid curves are the results of $l=3$ exact-finite-range calculations. There is evidence that the weakly excited state at 8.627 MeV has also a 5^- spin.

major contributor. Results from a study[28] of the (n,γ) reaction also provide evidence that both states have negative parity and spins between 1 and 4, with a tentative assignment of 2^-, 3^- to the level at 7.262 MeV and 3^- to the level at 7.282 MeV. From the present work and in view of the earlier results it would appear that an assignment of

TABLE III. Spectroscopic factors for several strong transitions to ^{26}Mg.

E_x (MeV)	J^π	l	S	(d,p)[a] S
6.878	3^-	3	0.15	0.50
		1	0.05	0.17
7.279	4^-	3	0.24[b]	3.7[c]
		1		1.48[c]
7.953	5^-	3	0.21	0.709
8.627	5^-	3	0.014	

[a]See Ref. 25.
[b]A spin of 4 has been assumed.
[c]Values listed are $(2J+1)S$ and primarily relate to a state at 7.262 MeV.

3^- or 4^- is most appropriate for the level at 7.282 MeV with some preference for the higher spin from systematics. Because the (d,p) spectroscopic factors are largely for the state at 7.262 MeV, it was not possible to use their $l=3$ to $l=1$ ratio for the state at 7.282 MeV.

The level at 7.953 MeV is again associated with a strong $l=3$ transition, as is seen in Fig. 6. This level is not listed in the 1976 compilation,[15] nor was it observed in the (n,γ) study.[28] Since no $l=1$ transfer was seen in the (d,p) work of Arciszewski *et al.*,[27] they assigned a spin and parity of $(5,6)^-$. In a study of the ^{23}Na$(\alpha,p\gamma)^{26}$Mg reaction, Glatz *et al.*[29] made assignments of 5^- to a level at 7.953 as well as 6^- to the state at 9.169 MeV. The 5^- assignment seems in complete agreement with all available evidence and the spectroscopic factor, listed in Table III, is quite comparable to that for the $(3,4)^-$ state at 7.279 MeV. With the state at 9.169 MeV which has been discussed previously and which is known to be 6^-, the four strongly excited states at 6.878, 7.279, 7.953, and 9.169 MeV are very likely 3^-, 4^-, 5^-, and 6^- states and are the major components of the $(d_{5/2},f_{7/2})$ configuration. The lowest state of each spin has the largest spectroscopic factor, as expected from the calcualtions of Zamick[26] for ^{28}Si.

The possible 5^- state at 8.625 MeV, known from the $(\alpha,p\gamma)$ study,[29] was very weakly excited in the present $(\alpha,^3\mathrm{He})$ work, but its angular distribution, also shown in Fig. 6, is characteristic of an $l=3$ transition. The spectroscopic factor is only 7% of that for the strong 5^- state at 7.953 MeV.

The $T=1$ analogs of these three strong $l=3$ transitions should manifest themselves in ^{26}Al through the (α,t) reaction. It is very likely that the state at 6.961 MeV in ^{26}Al which is known[11] to be strongly populated with an $l=3$ transition is the analog of the 3^- state in ^{26}Mg at 6.878 MeV. The spectroscopic factor in that case from the (α,t) study would be 0.18. The analog in ^{26}Al of the 7.279 MeV state in ^{26}Mg that is thought to be 4^- is not clearly defined. There is a large composite peak at about 7.3 MeV in ^{26}Al that has not been analyzed in the $7°$ (α,t) data that most probably contains the 4^- $T=1$ state under discussion. A pair of 5^- $T=1$ states has been identified in ^{26}Al at 8.002 and 8.058 MeV with spectroscopic factors of about 0.14 and 0.19, respectively.[11] It is interesting that only one strong 5^- $T=1$ state was seen in ^{26}Mg at 7.953 MeV. The sum of the spectroscopic factors for the two states in ^{26}Mg is 0.206, compared to the sum of 0.33 for the two states in ^{26}Al.

A rather simple relation is found for the total $f_{7/2}$ neutron stripping on ^{24}Mg and ^{25}Mg. The sum of spectroscopic factors to the 3.97 MeV and 7.28 MeV $\frac{7}{2}^-$ states of ^{25}Mg is 0.32, while the totals from Tables II and III for ^{26}Mg are 0.15, 0.24, 0.22, and 0.27 for the 3^-, 4^-, 5^-, and 6^- states, respectively. In a simple single-particle model, these should be the same and all equal to unity. Except for the 3^- transition, the equality is rather closely found. The 3^- states are endowed with greater collectivity, and it is not surprising that this multipolarity has a shortage of single-particle strength.

We have completed the stripping studies to the $T=1$ 6^- stretched states in mass 26, making available neutron and proton spectroscopic factors based on the ground state of ^{25}Mg to complement the scattering excitations based coherently upon all hole states. Discrepancies between neutron and proton stripping suggest isospin mixing, presumably in $T=0$ ^{26}Al.

All data to these 6^- states in mass 26 have been analyzed with the same single-particle wave functions, generated for a Woods-Saxon potential and including the unbound nature of some of the states. These results of neutron stripping, proton stripping[11] (at the same beam energy), and electron scattering[18] thus form a consistent and valuable test case for nuclear effects that spread and weaken the simple single-particle stretched state.

ACKNOWLEDGMENTS

The experiment was performed at the Research Center for Nuclear Physics under Program No. 21A19. One of us (J.J.K.) would like to thank the staff of the RCNP for their hospitality and support during the fall of 1985 when this experiment was carried out and the Foundation for Fundamental Research on Matter (FOM) of the Netherlands for support during the period when the analysis was carried out. This work was also partially supported by the U.S. Department of Energy.

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