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1^+ states of ^{26}Mg through the (α, ^{3}He) reaction at 81MeV

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Abstract

The ^{25}Mg (α, ^{3}He) ^{26}Mg reaction leading to seven 1^+ states, proposed previously by proton scattering at 201 MeV and by the (α, ^{3}He) reaction at 50MeV, was measured at $E_\alpha = 80.9$MeV. The cross sections obtained were analyzed within the framework of the exact-finite-range distorted wave Born approximation. The spectroscopic factors for a $d_{3/2}$ transfer to 1^+ states were compared with those predicted by sd shell model calculations. Two of the 1^+ states were found to have a simple ($d_{3/2}d_{5/2}$) structure consistent with the shell model picture. Others with too large $d_{3/2}$ transfer strength were ascribed owing to a mixture of other nearby states with J^π values other than 1^+ in referring to a recent compilation.

Key words: Nuclear Reaction (核反応)
Nuclear Structure (核構造)
Spectroscopic Factor (光学因子)
1^+ sates of ^{26}Mg (^{26}Mg核の1^+状態)

1 Introduction

Nuclear 1^+ states are particularly interesting for studies of the effective nucleon-nucleon spin-isospin interactions as long as the nuclear structure of 1^+ states is well known. Previously, Crawley et al.[1,2] studied 1^+ states of typical sd shell nuclei by 201 MeV proton inelastic scattering and analyzed forward-angle cross sections with the effective nucleon-nucleon interaction derived by Franey and Love[3] and with full sd shell model wave functions.[4] They obtained[2] a good agreement with the calculation for the transition strength and excitation energy for the T=2, 1^+ state of ^{26}Mg. On the other hand, the summed strength for the T=1, 1^+ states was 74% of the theoretical estimate and the individual strengths for each 1^+, T=1 state of ^{26}Mg showed large deviation from the prediction in comparison to the cases of other sd shell nuclei.

A complicated structure of the 1^+ states in ^{26}Mg was also suggested from the one-nucleon stripping reaction through comparative study[5] of the (α, ^{3}He) and (α, t) reactions on ^{25}Mg at E_α= 50MeV, where the spectroscopic factors for 1^+ states of ^{26}Mg were largely deviated from the shell model calculation,[6] while those for 1^+ states of ^{26}Al were consistent with the calculation. Besides, the (α, ^{3}He) experiment at 50MeV presented somewhat confusing results; the summed strength for the 1^+ states was two times or more larger than the limit of unity given in the pure j-j coupling scheme, and the (α, ^{3}He) angular distribution shapes for high-

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lying 1^+ states were not reproduced by DWBA calculations for a simple L=2 transfer. Thus, further experimental studies are required to solve those problems on the 1^+ states of ^{26}Mg.

In the present work, we have measured the ^{25}Mg (α, ^{3}He) ^{26}Mg reaction at higher incident energy than the previous one[5] in order to obtain more reliable spectroscopic information for a ($d_{3/2}$ $d_{5/2}$) component in the 1^+ states of ^{26}Mg. The (α, ^{3}He) transitions to other states except 1^+ states were reported elsewhere.[7]

2 Experimental procedure and results

The experiment was carried out using an 80.9MeV alpha beam from the AVF cyclotron at the Research Center for Nuclear Physics of Osaka University and the magnetic spectrograph system.[8, 9] Details of the experimental procedure were described in ref.7. Figure 1 shows a typical momentum spectrum at $\Theta_{lab}=5°$, where excitation energies of the 1^+ states proposed in the previous work[2, 5] are shown with those of other prominent peaks. The energy resolution at this angle is 25 keV FWHM (full width at half maximum). Namely, the same resolution as in the previous measurement[5] was achieved at the higher incident energy.

Figure 2 shows cross sections for the seven 1^+ states proposed from the previous work[2, 5], where curves, normalized to the data at forward angles, are exact-finite-range (EFR) DWBA calculations

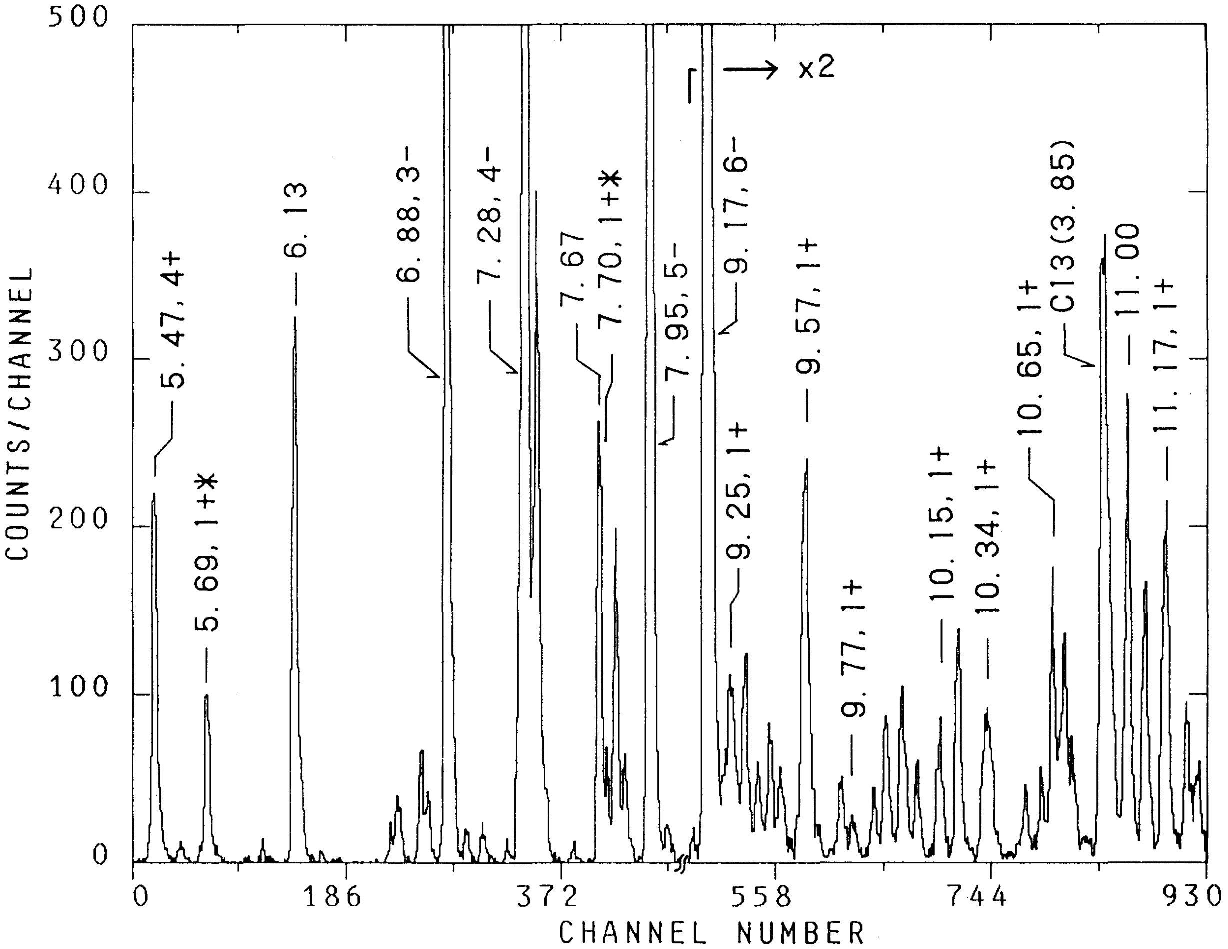

Fig.1 Momentum spectrum for the ^{25}Mg(α, ^{3}He) ^{26}Mg reaction at E_α=80.9MeV and Θ_{lab}=5° in the excitation energy regions of Ex =5.5MeV−8.0MeV and 9.2MeV−11.2MeV, where data in the latter region are displayed by multiplying a factor of 2. The 1^+ states with a mark * are proposed in ref.5, other 1^+ states are in ref.2. A spectrum in the range from Ex=0−15MeV at backward angles is given in ref. 7.

for a $d_{3/2}$ transfer with the code TWOFNR.[10] The parameters for the light particle form factors are described in ref.11. Potential parameters for the incident and outgoing channels and for the form factors are the same as in ref.7. Angular distribution shapes for these cross sections are fairy well reproduced by the DWBA calculations

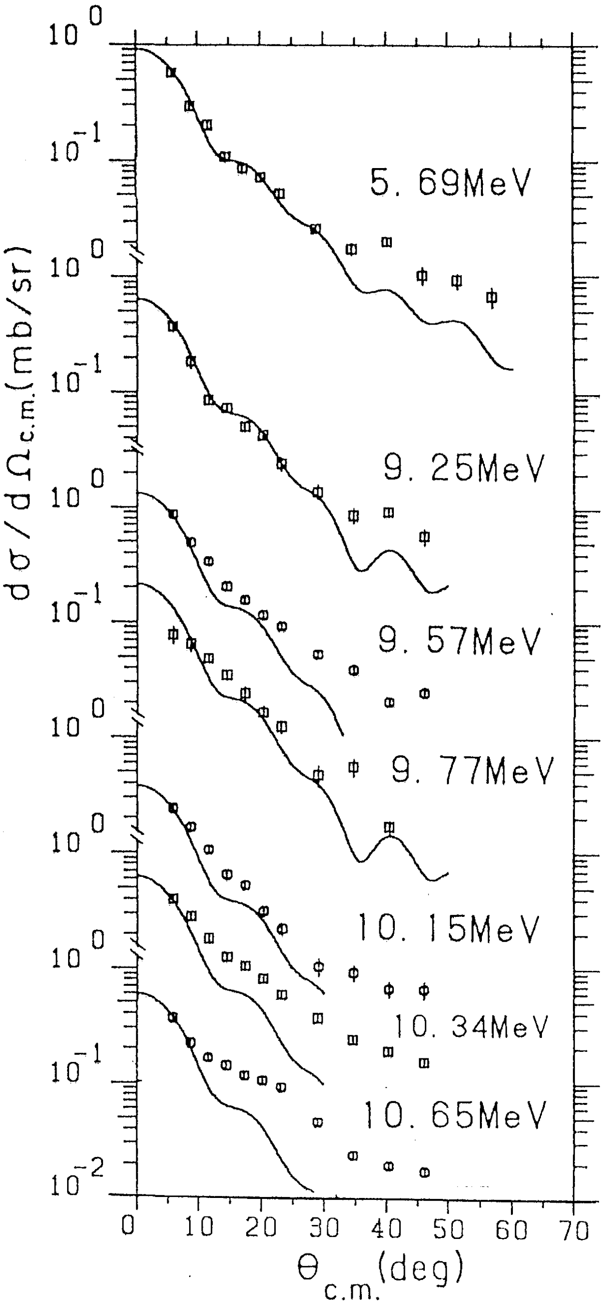

Fig.2 Cross sections for the ^{25}Mg (α, ^{3}He) ^{26}Mg reaction at Eα=80.9MeV leading to the 1^+ states proposed in refs. 2 and 5. Curves are EFR DWBA calculations for the $0d_{3/2}$ transfer. The cross sections for the 5.69MeV state are combined ones for the 5.69MeV 1^+ and 5.72 MeV 4^+ doublet.

compared to the case[5] at E_α=50MeV, suggesting that the (α, ^{3}He) transition to these 1^+ states at the present energy is more likely a one-step stripping process than at the lower energy.

The spectroscopic factors obtained are compared to the previous ones[5] and to the shell model calculations[6] in Table 1. Excitation energies with asterisk in the table indicate a state with a width wider than the experimental resolution in the observed spectrum in Fig. 1. As noted in a caption of the table, the broadness seems to be owing to a mixture of nearby two states.

Spectroscopic factors for narrow 1^+ states of 9.25MeV and 10.15MeV depend on the incident energy as seen in Table 1. Those at E_α=80.9MeV are smaller by a factor of 0.5 or 0.6 than the values at 50MeV, while those for broad states show more complex energy dependency with a factor ranging from 0.5 to 1.

3 Discussion and summary

Here, the energy dependence of a $d_{3/2}$ transfer in the ^{25}Mg(α, ^{3}He)reaction is inspected for the 4.90MeV 4_2^+, 5.47MeV 4_3^+ and 5.29MeV 2_5^+ states, which are described by the shell model[6] to have relatively a large $d_{3/2}$ component in addition to a smaller $d_{5/2}$ or $s_{1/2}$ component. In this case, spectroscopic information can be obtained from a comparison of the experimental and the calculated cross sections; $R=\sigma_{expt}/\sigma_{calc}$ and $\sigma_{calc}=C^2 s \Sigma S^j_{calc} \sigma^j_{TWO}$, where σ^j_{TWO} is the DWBA calculation for transferred angular momentum j and S^j_{calc} is spectroscopic factor predicted by the shell model, whose numerical values are given in ref.5. The isospin factor is $C^2=1$ and the light particle spectroscopic factor s=2. Obtained ratios at 80.9MeV (and 50MeV) are 0.57 (0.80), 0.72 (0.75) and 0.91(1.07) for the 4_2^+, 4_3^+ and 2_5^+ states, respectively, where the cross sections at 80.9MeV are almost similar in their angular distribution shapes to those[7] at 50MeV. Thus, much smaller energy

Table.1 Spectroscopic fctors for 1^+ states in ^{26}Mg observed in the ^{25}Mg (α, ^{3}He) ^{26}Mg reaction. Summed values are shown with a bracket < >, where the values in parenthesis below are only for the states with so narrow a width as to be clearly singlets.

Ex[a)]	Present work[b)]		previous[c)]	Shell model calculation[d)]		
(MeV)	σ_{INT} (mb)	S ($d_{3/2}$)[e)]	S ($d_{3/2}$)[e)]	S ($d_{5/2}$)	S ($d_{3/2}$)	Excalc (MeV)
5.69*	0.11	0.12	0.20	0.001	0.02	5.83
9.25	0.05	0.19	0.29	0.004	0.220	9.08
9.57*	0.17	0.42	0.52	0.002	0.076	9.14
9.77*	0.02	0.07	0.10	0.014	0.026	9.64
10.15	0.05	0.13	0.26	0.011	0.142	9.83
10.34*	0.11	0.23	0.23	0	0.037	10.28
10.65*	0.12	0.24	0.57	0	0.033	10.55
<Summed>		<1.4>	<2.17>	<0.065>	<0.647>	
		<(0.32)>	<(0.55)>	<(0.016)>	<(0.36)>	

a) cited from ref.5, b) Eα = 80.9MeV, c) Eα = 50MeV, d) ref.6 and numerical calculations were carried out with the code INS.[13]
e) Pure $d_{3/2}$ transfer is assumed. Excitation energies with a mark asterisk correspond to broad peaks in Fig.1. According to the compilation[12], the broadness suggests doublet states as follows: 5.69MeV; (5.691, 1^+ & 5.71, 4^+), 9.25MeV; (9.239, 1^+ & 9.579, 4^+), 9.77MeV; (9.771 & 9.779, 1^+), 10.34MeV; (10.319, 1^+ & 10.328, 5^-) and 10.65MeV; (10.646, 1^+ & 10.650)

dependences for the 4^+ and 2^+ states have been confirmed. The above mentioned 1^+ states with large widths and complex energy dependence in their spectroscopic factors are ascribed to doublet nature as noted in Table 1. However, the (p,p') data[2] obtained at 201MeV and at forward angles are expected to be sensitive mostly to the structure of 1^+ states themselves owing to the selectivity of the spin-flip transition.

The summed spectroscopic factor for the singlet-like 1^+ states, which is noted as a value in parenthesis in Table 1, is in good agreement with the shell model prediction, while the previous one[5] is 1.5 times larger than the prediction. The (α, ^{3}He)reaction leading to the 1^+ states is more momentum-mismatched at the incident energy of 81MeV than at 50MeV. Nevertheless, the present result has shown clearly the shell structure of the 1^+ states in ^{26}Mg. Thus, the present work indicates the usefulness of the (α, ^{3}He)reaction at 81MeV as a tool to investigate the shell structure of 1^+ states which are apt to be excited by coherent modes such as (p,p') scattering.

In the shell model picture, configurations of the 1^+ states of ^{26}Mg are described to be a mixture of ^{25}Mg(g.s., $5/2^+$) $xd_{3/2,5/2}$, ^{25}Mg($1/2^+$) x(sd) and ^{25}Mg($3/2^+$) x(sd) components. For instance, the model[6] predicts a two times larger amplitude of ^{25}Mg($3/2_1^+$) $xd_{3/2}$ component than that of ^{25}Mg($5/2_1^+$) $xd_{3/2}$ for 1_{10}^+ state, which corresponds to the 10.65 MeV state in Table 1. The one-step DWBA analyses, as seen in Fig.2 and Table 1, gave calculated cross sections for this state that deviate from the data in angular distribution shape and strength. However, the contribution of multi-step processes through the inelastic scattering channels is estimated to be only 10% of the calculated cross section for the direct $d_{3/2}$ transfer as long as the spectroscopic amplitudes obtained from the shell model are used in the second-order EFR DWBA calculations. Thus, the deviation in the cross section strength for the 10.65MeV state from the calculation cannot be explained even by taking account of these multi-step processes in the initial channels. The discrepancy may be reasonable to be owing to the doublet nature of the state as noted in Table 1.

In summary, the (α, ^{3}He) reaction at 81MeV was found to be a good probe for the spectroscopic study of 1^+ states in ^{26}Mg. The 9.25MeV 1^+ state, which is prominently excited by the proton inelastic scattering[2], was shown from the (α, ^{3}He) reaction to have a large ($d_{3/2}d_{5/2}$) component. Some of the 1^+ states reported in the previous work[5] were noticed to be composite levels, referring to the recent compilation by Endt et al.[12] On the other hand, singlet-like 1^+ states showed spectroscopic factors consistent with the shell model calculation[6]. Thus, the present work has revealed the reasonability of the sd shell model description to the distribution of the $0d_{3/2}$ component in the 1^+ states of ^{26}Mg.

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