Experimental investigation of $T = 1$ analog states of ^{26}Al and ^{26}Mg

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(Received 16 October 2015; revised manuscript received 15 January 2016; published 1 April 2016)

The even-even nucleus ^{26}Mg has been studied through the reaction ^{27}Al$(d,^3$He) at 25 MeV beam energy. The spectroscopic factors of the lowest ($T = 1$) states of ^{26}Mg have been extracted using the zero-range distorted wave Born approximation. These spectroscopic factors are compared with those of $T = 1$ analog states in ^{26}Al and found to be in good agreement.

DOI: 10.1103/PhysRevC.93.044601

I. INTRODUCTION

In nuclear interactions, isospin symmetry plays a significant role as it directly reflects the charge-symmetric and charge-independent characteristics of nuclear interactions. In the case of isobaric analog states of isobaric multiplets, isospin (T) becomes a good quantum number as it couples the concept of charge symmetry with the charge independence and Pauli exclusion principle. Isobaric analog states are defined as the states in isobars having the same angular momentum, parity, and isospin but with different z component of isospin (t_z). So, single neutron and proton pick-up and/or stripping reactions may be used as good tools to study analog isobars and the importance of isospin.

In recent years, there has been intensive study on the nucleus ^{26}Al (as well as ^{26}Mg, the radioactive β^+ decay product of ^{26}Al) for its importance in gamma-ray astronomy to understand the evolutionary scenario of nucleosynthesis in the stars [1]. Apart from its importance in astrophysics, ^{26}Mg is also interesting from a nuclear physics point of view, as it forms an isobaric doublet with ^{26}Al. Therefore, the ^{26}Mg -^{26}Al pair may be investigated for the study of isospin symmetry in nuclei via isobaric analog states. Such attempts have been made earlier to study the isobaric analog states in these nuclei using α–$t/^3$He reactions [2]. So, the primary motivation of the present study was to study the $T = 1$ analog states in ^{26}Al and ^{26}Mg using a different (d–$t/^3$He) reaction sequence, which has not been reported earlier, to the best of our knowledge. Here we report an experimental study of the low-lying $T = 1$ states of ^{26}Mg populated through the ^{27}Al$(d,^3$He) reaction at 25 MeV and the comparison of the extracted spectroscopic factors (S) of those states with their corresponding analog states in ^{26}Al, also studied recently by the present authors [3].

II. EXPERIMENT AND DATA ANALYSIS

The experiment was performed using a 25 MeV deuteron beam from the K130 Cyclotron on a self-supported ^{27}Al (thickness $\sim$90 μg/cm^2) target at the Variable Energy Cyclotron Centre, Kolkata. Data for the (d,t) and $(d,^3$He) reactions were taken simultaneously, and the experimental details are given in [3]. The optical model potential (OMP) parameters used in the calculation are given in Table I. Details of the procedure are available in our previous paper [3]. Three $T = 1$ analog states (ground, 1806, and 2935 keV states) of ^{26}Mg have been chosen in the present paper for detailed analysis. The measured angular distributions of these three states are shown in Fig. 1. Spectroscopic factors of these states of ^{26}Mg were extracted using the relation [4]

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{exp.}} = 2.95\frac{C^2S}{2J+1}\left(\frac{d\sigma}{d\Omega}\right)_{\text{DWUCK4}}, \qquad (1)$$

where $(\frac{d\sigma}{d\Omega})_{\text{exp.}}$ is the experimental differential cross section, $(\frac{d\sigma}{d\Omega})_{\text{DWUCK4}}$ is the cross section predicted by the zero-range distorted wave Born approximation (DWBA) computer code DWUCK4 [5], J is the total angular momentum of the orbital from where the proton is picked up, S is the spectroscopic factor, and C^2 is the isospin Clebsch-Gordon coefficient.

All three states were analyzed assuming pick-up from $0d_{5/2}$ and $1s_{1/2}$ orbitals; moreover, the 1806 and 2935 keV states were also tested for $0d_{5/2} + 1s_{1/2}$ configuration mixing. We used two combinations of the potential parameters (e.g., A-B and A-C) to extract the spectroscopic factors of the $T = 1$ states of ^{26}Mg. The results of the DWBA analysis are displayed in Fig. 1 along with the experimental data for comparison, and the extracted C^2S values are tabulated in Table II (for details of the procedure, see [3]). It is clear from Fig. 1 that the angular distributions are strongly dominated by $l = 2$ transfer as compared to $l = 0$ transfer. So, we may ignore the role of configuration mixing for these states. Typical uncertainties (shown in Table II) in the extracted C^2S values were approximately 25% for $l = 2$ transfer (for details, see [8]).

III. DISCUSSION

In the DWBA analysis of transfer reactions, isospin symmetries are usually taken into account through isotopic

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TABLE I. The best fit potential parameters used in DWUCK4 code for the ^{27}Al(d,^{3}He) reaction. V^p is the well depth, adjusted to give the required separation energy for the transferred particle.

Reaction	Set	V (MeV)	R_o (fm)	a_o (fm)	W_v (MeV)	W_D (MeV)	R_I (fm)	a_I (fm)	V_{ls} (MeV)	R_{ls} (fm)	a_{ls} (fm)	R_C (fm)
$d + ^{27}$Al	A [3]	89.209	1.061	0.701		2.250	1.360	0.850	9.00	1.061	0.801	1.25
^{3}He $+^{26}$Mg	B [6]	151.97	1.20	0.720	37.75		1.400	0.880	2.50	1.20	0.720	1.30
	C [7]	217.6	1.15	0.636	32.5		1.319	0.986				1.40
$p + ^{26}$Mg		V^p	1.20	0.650								1.25

Clebsch-Gordan coefficients [$C^2 = 1/3$ and 2/3, for ^{27}Al(d,t)^{26}Al and ^{27}Al(d,^{3}He)^{26}Mg, respectively]; therefore, the spectroscopic factor, S, for isobaric analog states of isobaric multiplets should be identical. So, the spectroscopic factors of $T = 1$ isobaric analog states of ^{26}Al obtained in our previous work [3] were compared with those for the corresponding analog states of ^{26}Mg observed in the present work. The comparison is given in Table II, where it is clearly evident that the ratio of spectroscopic factors of the analog states is $\simeq$1 in all cases, within the limits of experimental uncertainties. So, one can draw the conclusion from Table II that the analog states are appreciably excited, reflecting the importance of isospin symmetry in nuclear interactions. The present results on the ratio of extracted S values of isobaric analog states were also compared in Table II with the values (given in [2]) obtained from the stripping reaction sequence ^{25}Mg(α,^{3}He) and ^{25}Mg(α,t), and the ratios were found to be in good agreement. Particularly for the 230 keV state of ^{26}Al (and ground state of ^{26}Mg), the present result is more consistent (closer to 1–1.04 against 1.33 reported earlier), confirming their analog characteristics.

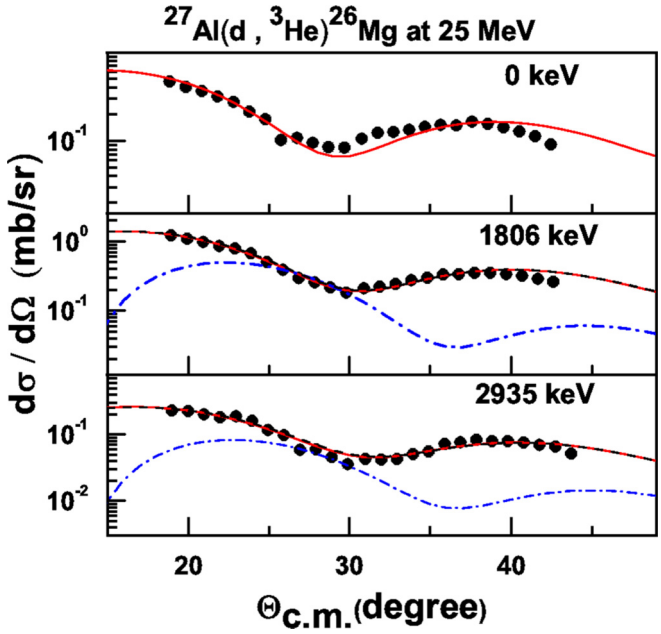

FIG. 1. Angular distributions for ground, 1806, and 2935 keV states. The filled circles represent experimental data points. The solid, dash-dot-dash, and dash-dash lines represent the theoretical cross sections for pickup from $0d_{5/2}$, $1s_{1/2}$, and $0d_{5/2} + 1s_{1/2}$ mixing respectively for the combination A-B.

IV. CONCLUSION

In conclusion, the reaction ^{27}Al(d,^{3}He)^{26}Mg was studied at 25 MeV beam energy and analyzed using the zero-range distorted wave Born approximation. Spectroscopic factors for the previously identified $T = 1$ analog states in ^{26}Mg were extracted and compared with those of their analog counterparts in ^{26}Al. The extracted ratio of spectroscopic factors for the analog states were found to be $\sim$1 for all three states, confirming the similarity of structure of the states as expected for analog states.

ACKNOWLEDGMENTS

The authors thank the cyclotron operating staff for their cooperation during the experiments. One of the authors (A.D.) acknowledges with thanks the financial support provided by the Science and Engineering Research Board, Department of Science and Technology, Government of India via Project No. SR/FTP/PS067/2012. One of the authors (S.B.) acknowledges with thanks the financial support received as a Raja Ramanna Fellow from the Department of Atomic Energy, Government of India.

TABLE II. Comparison of spectroscopic factors (S) of analog states from the reactions ^{27}Al(d,t)^{26}Al and ^{27}Al(d,^{3}He)^{26}Mg at 25 MeV for $T = 1$. Errors in C^2S are about 25%.

E_x[a] (keV)	C^2S[a]	J^π	E_x[b] (keV)	C^2S[b]	$\frac{S(^{26}\text{Al})}{S(^{26}\text{Mg})}$[c]	$\frac{S(^{26}\text{Al})}{S(^{26}\text{Mg})}$[d]
230	0.09	0^+	0	0.17	1.04	1.33
2070	0.26	2^+	1806	0.57	0.91	1
3160	0.06	2^+	2935	0.13	0.92	1

[a]Taken from the study of the reaction ^{27}Al(d,t) [3].
[b]Present study of the reaction ^{27}Al(d,^{3}He).
[c]Ratio obtained from footnotes a and b.
[d]Ratio obtained from [2].

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