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Isospin forbidden (α,d) transitions to the low-lying states in ^{26}Al

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The ^{24}Mg$(\alpha,d)^{26}$Al reaction leading to the 0.23 MeV 0_1^+, $T=1$ and the 3.16 MeV 2_2^+, $T=1$ states were measured at $E_\alpha=64.7$ MeV. Cross sections for these isospin-forbidden transitions were compared with exact-finite-range second-order distorted wave Born approximation (DWBA) calculations for successive-transfer processes (α-^{3}He-d) and (α-t-d). The DWBA calculation with spectroscopic amplitudes obtained from the full *sd*-shell model was found to underestimate the cross section for the 0^+ state by a factor of 200, while a normalization factor of 10 was obtained for the 2^+ state. About 5% isospin impurity in the 0^+ state of ^{26}Al was required to obtain the same normalization for the 0^+ state.

Low-lying states of ^{26}Al have been studied by nuclear reactions such as (p,γ),[1] by one-nucleon transfer,[2] and charge exchange (p,n),[3] and found to be well described by the *sd*-shell model wave functions of Wildenthal.[4] Furthermore, unequal spectroscopic factors were noticed[2] for some analog transitions in the $(\alpha,{}^3\mathrm{He})$ and (α,t) reactions on ^{25}Mg. The spectroscopic factor for the 0.23 MeV $0_1^+,T=1$ state of ^{26}Al was 30% larger than that for the analog state in ^{26}Mg. On the other hand, the strengths of the analog transitions to the 2_1^+ and 2_2^+ states of ^{26}Al and ^{26}Mg were found to be about equal. The unequal transition strengths for the 0^+ states suggest mixing of higher-order configurations with different proton and neutron components. However, the shell model[4] describes the structure of the state to be symmetric between proton and neutron. It is hoped for, therefore, to inspect the isospin properties of the 0^+ states with other reactions. The ^{24}Mg$(\alpha,d)^{26}$Al reaction can be a sensitive and independent probe for the investigation of the isospin structure of the ^{26}Al states, especially of the $0^+,T=1$ state.

An (α,d) transition from the $0^+,T=0$ target to the $0^+,T=1$ state is forbidden in terms of both spin and isospin selection rules as long as the transition is a direct one-step process. Izumoto showed[5] that the $\Delta T=1(d,\alpha)$ transition to the $0^+,T=1$ state of ^{10}B can be explained by successive nucleon transfer processes (d-^{3}He-α) and (d-t-α). Similarly, successive-transfer processes such as (α-^{3}He-d) and (α-t-d) allow the (α,d) transition to the $T=1$ states of ^{26}Al and can be a sensitive probe for the isospin mixture, since these two processes interfere destructively for the $\Delta T=1$ transfer and constructively for the $\Delta T=0$ transfer.

In the present work, we have measured the (α,d) cross sections for the 0.23 MeV $0_1^+,T=1$ and the 3.16 MeV $2_2^+,T=1$ states of ^{26}Al and compared them with second-order DWBA calculations for the successive-transfer processes in order to investigate the isospin purity of these states.

The experiment was carried out using a 64.7 MeV alpha beam from the sector-focusing cyclotron at the Institute for Nuclear Study of the University of Tokyo and the magnetic spectrometer system.[6] A self-supporting ^{24}Mg target of 0.45 mg/cm^2 in thickness and of 99.92% in enrichment was used. Details of the experimental procedure are described in Ref. 7. Figure 1 shows a typical momentum spectrum at $\theta_{\mathrm{lab}}=25°$. Small but isolated peaks for the $T=1$ states at $E_x=0.23$ MeV and 3.16 MeV are seen in the figure. These peaks were confirmed in spectra at different angles as well as in those obtained with a thinner target. A peak corresponding to the 4.19 MeV, $3^+,T=1$ state is also observed in Fig. 1. Cross sections for this spin-allowed, isospin-forbidden transition were reported elsewhere.[8]

Obtained cross sections for these states are only a few μb/sr even at forward angles but still have diffractive angular distribution shapes as shown in Fig. 2. If the spin-isospin-forbidden (α,d) transition to the $0^+,T=1$ state was due to compound reaction processes, the angular distribution shape should be near isotropic. The observed diffractive shape suggests contributions of successive-transfer processes such as (α-^{3}He-d) and (α-t-d) to these

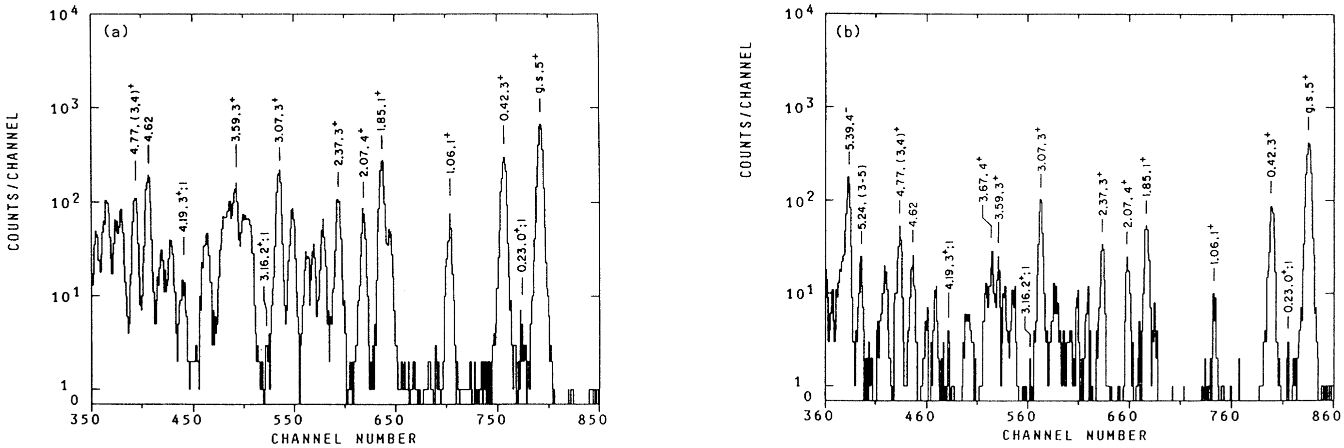

FIG. 1. A typical momentum spectrum for the ${}^{24}\mathrm{Mg}(\alpha,d){}^{26}\mathrm{Al}$ reaction at $E_\alpha=64.7$ MeV and at $\theta_{\mathrm{lab}}=25°$. Overall resolution was about 50 keV FWHM. Each peak in the figure is labeled by its excitation energy in MeV and the spin parity of the state.

(α,d) transitions.

Therefore, exact-finite-range second-order DWBA calculations were carried out with the code TWOFNR (Ref. 9) following the procedure described in Ref. 10 by taking the first $\frac{5}{2}^+$, $\frac{1}{2}^+$, and $\frac{3}{2}^+$ states[11] in ${}^{25}\mathrm{Mg}$ and ${}^{25}\mathrm{Al}$ as the intermediate states in the successive-transfer channels. Spectroscopic amplitudes for the successive-transfer processes were obtained from the full *sd*-shell model[4] with the code INS,[12] and are given in Fig. 3. The same potential parameters as in Ref. 13 were used for ${}^{3}\mathrm{He}$ and *t* and for the form factors. Potential parameters for α and *d* were obtained from Refs. 14 and 15, respectively.

Curves in Fig. 2 are the results of the calculations for the successive-transfer terms (dashed), the nonorthogonal terms (dotted), and the coherent sum (solid) of them. The calculated cross sections in Fig. 2 for the 0^+ and the 2^+

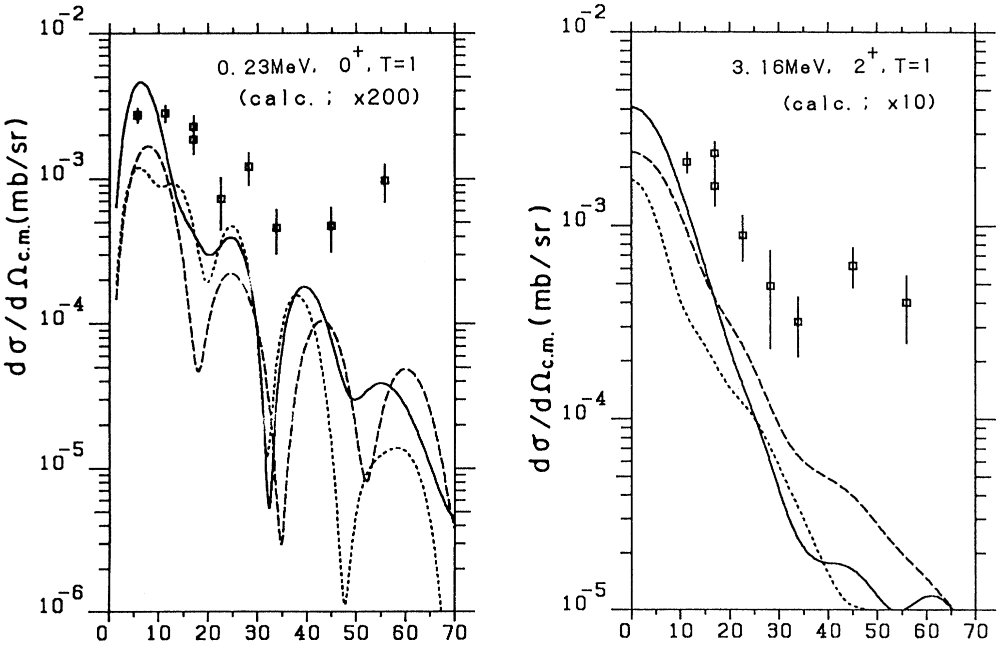

FIG. 2. Cross sections for the ${}^{24}\mathrm{Mg}(\alpha,d){}^{26}\mathrm{Al}$ reaction at $E_\alpha=64.7$ MeV leading to the 0.23 MeV $0^+,T=1$ and the 3.16 MeV $2^+,T=1$ states. Curves are exact-finite-range DWBA calculations for the successive transfer (dashed) $(\alpha\text{-}{}^{3}\mathrm{He}\text{-}d)$ and $(\alpha\text{-}t\text{-}d)$, the nonorthogonal terms (dotted), and the coherent sum of them (solid curve). The curves are normalized to the data as noted in the figure.

states are multiplied by a factor of 200 and 10, respectively.

The DWBA calculations (solid curves in Fig. 2) underestimate the cross sections although they reproduce the angular distribution shapes at forward angles. Extension of the intermediate channels to include the second $\frac{5}{2}^+$, $\frac{1}{2}^+$, and $\frac{3}{2}^+$ states in ^{25}Mg and ^{25}Al only slightly modifies the results, since the successive-transfer cross sections going through these states are an order of magnitude smaller. Thus the large discrepancy between the experimental and the calculated (α,d) cross sections for the $0^+,T=1$ state presents a serious problem. DWBA calculations for the one-nucleon transfer reactions $(\alpha,{}^3\mathrm{He})$ (Ref. 2) and $({}^3\mathrm{He},d)$,[13] on the contrary, are known to reproduce the experimental cross sections for these states in ^{26}Al and give strengths in agreement with the shell model predictions.[4]

About 3% mixture of the $T=0$ component in the 0.23 MeV 0^+ state of ^{26}Al was suggested from a comparison[2] of the $(\alpha,{}^3\mathrm{He})$ and (α,t) reactions on ^{25}Mg. The calculated two-step cross section for this state would increase, if such a mixture exists, owing to the constructive interference of the $(\alpha\text{-}{}^3\mathrm{He}\text{-}d)$ and $(\alpha\text{-}t\text{-}d)$ amplitudes. Indeed, the normalization factor decreases to 10 if we allow 5% $T=0$ mixture in the 0.23 MeV state, which is close to the value suggested from the $(\alpha,{}^3\mathrm{He})$ and (α,t) results. A normalization factor of 10 thus obtained is consistent with those required for the (α,d) transitions to other $T=1$ states in ^{26}Al such as the 3.16 MeV $2^+,T=1$ state discussed here, and the 9.26 MeV $6^-,T=1$ state. The (α,d) data for the latter state, thought to be of the $(d_{5/2}f_{7/2})$ configuration, were reported in Ref. 16. These 2^+ and 6^- states are thought to be pure $T=1$ states as discussed in Ref. 2. Thus the normalization factor of 10 for the successive transfer to the $T=1$ states in ^{26}Al is required not only for the well-bound low-lying states but also for the unbound 6^- state as long as we assume the isospin mixture in the 0^+ state. If we try to explain the discrepancies between the calculations and the data solely by the isospin mixing, we need 50% $T=0$ mixture for the 0^+ state and 10% $T=0$ mixture for the 2^+ state. Such large isospin mixings are very unlikely from the one-nucleon transfer results.

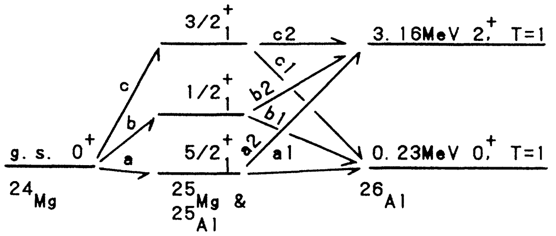

FIG. 3. Level diagrams for the successive nucleon transfer from the 0^+ ground state of ^{24}Mg to the 0.23 MeV $0^+,T=1$ and the 3.16 MeV $2^+,T=1$ states of ^{26}Al. Amplitudes for the transitions indicated in the figure are (a) $0.585D5$, (b) $0.696S1$, (c) $0.486D3$, (a1) $1.580D5$, (b1) $0.415S1$, (c1) $0.202D3$, (a2) $-0.298D5-0.670S1-0.027D3$, (b2) $-0.433D5-0.091D3$, and (c2) $-0.483D5+0.025S1+0.131D3$. Symbols $D5$, $S1$, and $D3$ denote the $0d_{5/2}$, $1s_{1/2}$, and $0d_{3/2}$ components, respectively.

Effects of projectile breakup channels were neglected in the present analysis. Recently Shyam *et al.*[17] showed an important role of Coulomb force on the α-induced breakup processes. Such projectile breakup channels may be relevant to the observed discrepancy between the calculated and the experimental (α,d) cross sections for the $T=1$ states.

In summary, we have measured the cross sections for the isospin-forbidden transitions in the $^{24}\mathrm{Mg}(\alpha,d)^{26}\mathrm{Al}$ reaction exciting natural-parity $T=1$ states in the residual nucleus, and compared them with exact-finite-range second-order DWBA calculations for successive-transfer processes $(\alpha\text{-}{}^3\mathrm{He}\text{-}d)$ and $(\alpha\text{-}t\text{-}d)$. The observed strength for the 0^+, $T=1$ state of ^{26}Al is consistent with about 3% mixture of $T=0$ impurity suggested from the results of the one-nucleon stripping reactions on ^{25}Mg. The present successive-transfer calculations underestimate the $\Delta T=1$ (α,d) transitions by an order of magnitude, suggesting necessity of more refined treatments of such weak transitions.

Numerical calculations were carried out with the central computers at Research Center for Nuclear Physics of Osaka University and at Kantogakuin University.

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