Bull. Inst. Chem. Res., Kyoto Univ., Vol. 60, No. 2, 1982

The (^{6}Li, d) Reaction on ^{40}Ca at 76 MeV

Tetsumi TANABE*, Kouya OGINO, Yusaku KADOTA, Kaiichi HAGA**,
Tetsuo SHIBA***, and Tetsuo KITAHARA****

Received March 15, 1982

The ^{40}Ca(^{6}Li, d)^{44}Ti reaction has been studied at 76-MeV bombarding energy. The angular distributions have been analyzed with exact finite-range DWBA calculations assuming a direct α-cluster transfer. Alpha-particle spectroscopic factors are extracted for low-lying states of ^{44}Ti and compared with those from the theory which combines the shell model with the ^{40}Ca-α cluster model.

KEY WORDS: (^{6}Li, d) Reaction/ ^{40}Ca Target/ EFR-DWBA Calculation/ Alpha-Particle Spectroscopic Factor/

I. INTRODUCTION

Many experimental and theoretical studies have been done recently on the ^{44}Ti nucleus which has the basic structure consisting of four valence nucleons around the ^{40}Ca core. Although many properties for the low-lying levels of ^{44}Ti are explained, some problems are still unsolved. Experimental studies for ^{40}Ca(^{6}Li, d)^{44}Ti by Fulbright *et al.*[1] and Strohbusch *et al.*[2] find that the α-particle spectroscopic factors for the ground-state band decrease with increasing spin values, while a shell-model predicts the spectroscopic factors which are nearly constant and do not decrease with spin values.[3] The structure of ^{44}Ti was also studied recently by Itonaga[4] in an extended model which combines the shell model with the ^{40}Ca-α cluster model. Although this model predicts correctly the observed tendency of spectroscopic factors as a function of spin values, the agreement between theory and experiment is quantitatively still unsatisfactory. Experimental spectroscopic factors from the ^{40}Ca(^{6}Li, d)^{44}Ti reaction reported to data are only in low bombarding energies around 30 MeV. We have measured angular distributions for the ^{40}Ca(^{6}Li, d)^{44}Ti reaction at 76 Mev to study the sensitivity of spectroscopic factors to variations in bombarding energy, since our previous work on ^{16}O(^{6}Li, d)^{20}Ne reaction at 75 MeV[5] led to different results from those at low bombarding energies for the α-particle spectroscopic factors of the ^{20}Ne ground-state band. The spectroscopic factors for the α-particle transfers are obtained by comparing the data with exact finite-range DWBA calculations that use measured optical model parameters to generate the distorted waves in the entrance channel.

* 田辺徹美: Institute for Nuclear Study, University of Tokyo, Tanashi, Tokyo
** 荻野晃也, 門田勇作, 芳賀開一: Department of Nuclear Engineering, Faculty of Engineering, Kyoto University, Kyoto
*** 芝 哲夫: Laboratory of Nuclear Reaction, Institute for Chemical Research, Kyoto University, Kyoto
**** 北原哲夫: Yamanashi Medical College, Nakakomagun, Yamanashi

II. EXPERIMENTAL PROCEDURE

The experiment was performed with a 75.8-MeV $^6Li^{3+}$ beam[6] obtained from the cyclotron at the Institute for Nuclear Study. The beam intensity on the target was about 50 nA. A self-supporting natural Ca metal foil was used as a target. The thickness was estimated by normalizing the elastic scattering data of 76-MeV ^{6}Li on ^{40}Ca to the curve calculated with optical potential parameters at forward angles. The thickness of Ca determined by this method was 0.53 mg/cm^2.

Outgoing deuterons were momentum analyzed by using a QDD spectrograph and then detected in a position-sensitive proportional counter placed in the focal plane of the spectrograph[7]. The deuteron was identified with a ΔE proportional counter which was located behind the position-sensitive counter and with time of flight which was measured by the time difference between rf-signal from the cyclotron and signal from a plastic scintillation counter placed behind the proportional counter. The energy resolution was about 200 keV mainly due to the target thickness. The beam and target were monitored by a 1 mm surface barrier detector.

III. ANALYSIS PROCEDURE

III. 1. Elastic Scattering

The optical potential parameters of ^{6}Li on ^{40}Ca were searched for by using an automatic search code SEARCH.[8] The optical parameters of ^{6}Li were based upon potentials determined at 50.6 MeV by Chua *et al.*[9] with the real depth (V) and the imaginary depth (W) adjusted to fit our 76-MeV ^{6}Li elastic data holding other parameters fixed during search. The parameters listed in Table I provided an adequate fit to the angular distributions of elastically scattered ^{6}Li as shown in Fig. 1.

For the exit channel, we used the average deuteron parameter set 1 with inclusion of spin-orbit coupling term given by Hinterberger *et al.*[10]

TABLE I. Optical model parameters of ^{6}Li on ^{40}Ca used in the DWBA analysis of the reaction ^{40}Ca(^{6}Li, d)^{44}Ti at 75.8 MeV. W is the depth of the volume-type imaginary potential.

Channel	V (MeV)	r_R (fm)	a_R (fm)	W (MeV)	r_I (fm)	a_I (fm)	r_C (fm)
^{6}Li+^{40}Ca	185.8	1.3	0.7	29.0	1.7	0.9	1.4

III. 2. The (^{6}Li, d) Reaction

An exact finite-range (EFR) DWBA analysis was performed with the code TWOFNR[11] to deduce the spectroscopic factor (S_α) assuming a direct one-step transfer of α-particle cluster. The parameters of ^{6}Li with $\alpha+d$ system in a relative 2S state and those of bound states for ^{44}Ti are the same as those used in our previous paper.[12] The

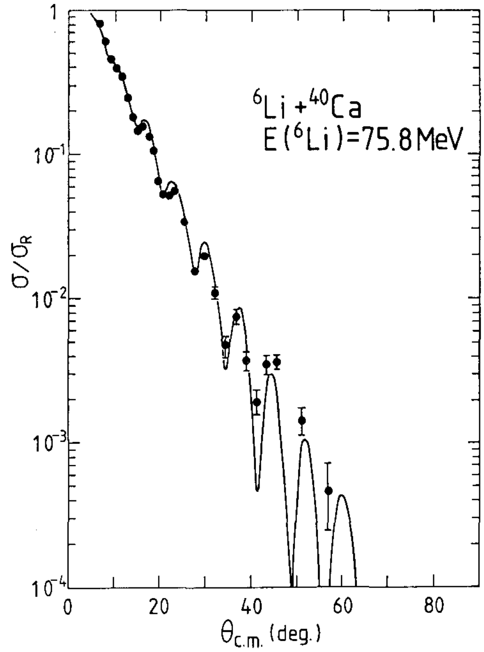

Fig. 1. Experimental angular distributions for 75.8-MeV ^{6}Li elastic scattering on ^{40}Ca. The curve shows the results of the optical model calculations.

number of radial nodes for the bound state wave function was fixed by the oscillator energy conservation relation, assuming the configuration $(fp)^4$ of the transferred four nucleons for even parity states.

IV. RESULTS AND DISCUSSIONS

A deuteron spectrum resulting from the ^{40}Ca(^{6}Li, d)^{44}Ti reaction at 10° is shown in Fig. 2. The strong impurity lines from carbon and oxygen contaminants are seen in the spectrum. The carbon and oxygen impurities present in the target have cross sections for the same reaction an order of magnitude greater than do those of interest. They prevented observations of some groups at particular angles and masked others at all angles. Therefore only low-lying states are resolved.

Figure 3 shows the experimental and calculated (^{6}Li, d) angular distributions for the low-lying states in ^{44}Ti. The EFR DWBA curves are normalized to data in order to extract S_α values. Relative spectroscopic factors S_α/S_α^{gs} extracted from this experiment are compared with those from (^{6}Li, d) data at 28 MeV[1] and 32 MeV[2] in Fig. 4. The values from the theory[4] are also shown. The 2.45 MeV 4^+ level could not be resolved from 2.53 MeV level and the experimental strength is the sum over the two levels in Fig. 3. The S_α/S_α^{gs} value for this level which is shown with asterisk in Fig. 4 was extracted assuming only L=4 angular distribution and therefore should be regarded as the upper limit of the spectroscopic factor.

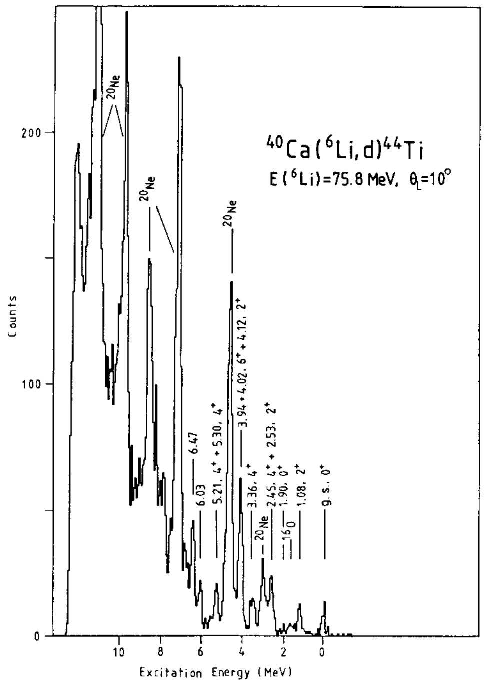

Fig. 2. Spectrum of deuterons from the reaction ^{40}Ca(^{6}Li, d) ^{44}Ti at E(^{6}Li) = 75.8 MeV and $\theta_L = 10°$.

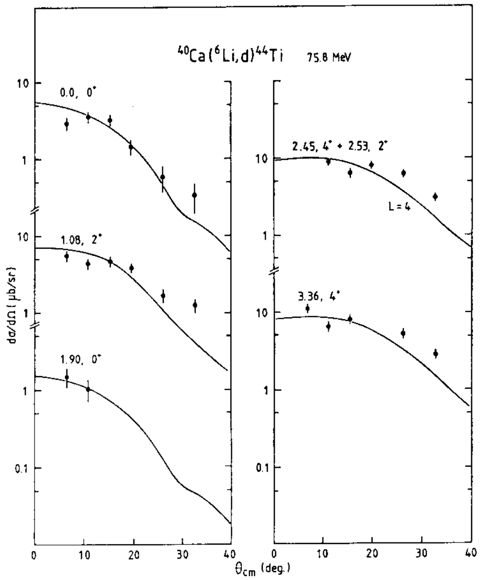

Fig. 3. Angular distributions of the reaction ^{40}Ca(^{6}Li, d) ^{44}Ti. Curves represent EFR DWBA calcultions. Error bars indicate only statistical errors.

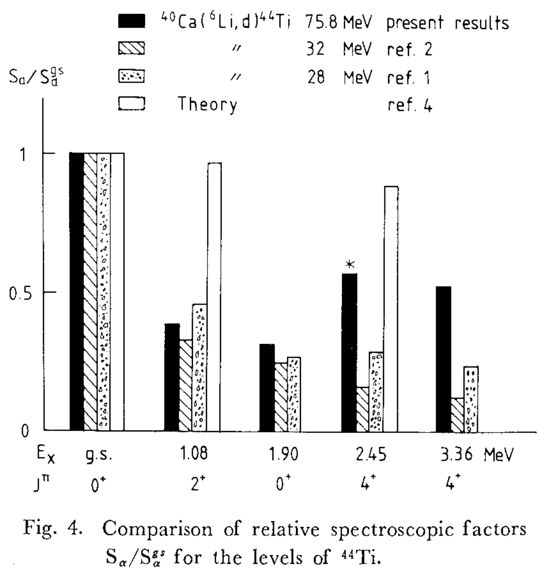

Fig. 4. Comparison of relative spectroscopic factors S_α/S_α^{gs} for the levels of ^{44}Ti.

Absolute value of S_α^{gs} extracted from the data for the ground state transition is 0.34, assuming a value of 1.0 for the $^6Li \rightarrow \alpha + d$ spectroscopic factor, while the theoretically predicted value is 0.137.[4] Since the calculated cross sections vary greatly with small change in bound state radius, the spectroscopic factors cannot be considered to be well determined unless the bound state parameters are very well known. Therefore one should not rely strictly upon the absolute spectroscopic factors.

The values of S_α/S_α^{gs}, on the other hand, can be less ambiguously extracted, since the relative cross sections vary little with change in bound-state parameters or optical model parameters as described previously.[5] As seen in Fig. 4, the values of S_α/S_α^{gs} for the 2_1^+ and 0_2^+ levels are consistent with those from the experiments at low bombarding energies and the value for the 4_2^+ is slightly larger than those at low bombarding energies. On the other hand, theoretical values are considerably larger than those from experiments for the 2_1^+ and 4_1^+ levels. The strong decrease in the S_α/S_α^{gs} values of the ground-state band members with increasing spin contrasts with corresponding results[5] for the ground-state band of ^{20}Ne. This decrease which is probably due to the enhancement of the strength in $^{44}Ti_{gs}$ appears to mean more complex configurations including core polarization.[3]

In the (^{6}Li, d) experiments at low bombarding energies, it has been shown that intensities of unnatural parity states relative to normal-parity states are stronger in the lighter targets particulary in sd shell nuclei than in fp shell nuclei.[1] From this result it has been suggested that the difference between sd and fp shell experiences may be due to the presence of compound nucleus reaction mode in the reaction mechanism. If such a suggestion is right, the sensitiveness of S_α/S_α^{gs} values extracted from (^{6}Li, d) data to variations in bombarding energy for ground-state band members of ^{20}Ne[5] and the insensitiveness of them for those of ^{44}Ti can be understood qualitatively as due to the different contribution of the compound reaction mechanism.

Experimentally the target impurities have to be reduced to observe higher levels. Further experimental work is desirable to study the α-particle spectroscopic strengths for these levels.

ACKNOWLEDGEMENTS

We thank Mr. I. Sugai for the target preparations. Thanks are also due to the cyclotron crew for their support and members of the computer section for the use of FACOM-M180 II AD computer.

REFERENCES

(1) H. W. Fulbright, C. L. Bennett, R. A. Lindgren, R. G. Markham, S. C. McGuire, G. C. Morrison, U. Strohbusch and J. Toke, *Nucl. Phys.* **A284**, 329 (1977).
(2) U. Strohbusch, C. L. Fink, B. Zeidman, R. G. Markham, H. W.Fulbright and R. N. Horoshko, *Phys. Rev.* **C9**, 965 (1974).
(3) C. L. Bennett, *Nucl. Phys.* **A284**, 301 (1977).
(4) K. Itonaga, *Prog. Theor. phys.* **66**, 2103 (1981).
(5) T. Tanabe, M. Yasue, K. Sato, K. Ogino, Y. kadota, Y. Taniguchi, K. Makino and M. Tochi, *Phys. Lett.* **100B**, 241 (1981).

(6) T. Tanabe, Y. Ohshiro and K. Sato, *Nucl. Instrum. Methods*, **178**, 315 (1980).
(7) S. Kato, T. Hasegawa and M. Tanaka, *Nucl. Instrum. Methods*, **154**, 19 (1978).
(8) T. Wada, Institute of Physical and Chemical Research report **46**, 21 (1970).
(9) L. T. Chua, F. D. Becchetti, J. Jänecke and F. L. Milder, *Nucl. Phys.* **A273**, 243 (1976).
(10) F. Hinterberger G. Mairle, U. Schmidt-Rohr and G. J. Wagner, *Nucl. Phys.* **A111**, 265 (1968)
(11) M. Igarashi, computer code TWOFNR, unpublished.
(12) T. Tanabe, M. Yasue, K. Sato, K. Ogino, Y. Kadota, Y. Taniguchi, K. Obori, K. Makino and M. Tochi, *Phys. Rev.* **C24**, 2556 (1981).