2.A.1 : 2.B

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CROSS-SECTION MEASUREMENTS FOR THE ^{6}Li(p, α)^{3}He REACTION IN THE PROTON ENERGY RANGE 1.0–2.6 MeV

CHIA-SHOU LIN, WAN-SHOU HOU, MIN WEN and JEN-CHANG CHOU

Institute of Nuclear Energy Research, Lung-Tan, Taiwan, Republic of China

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Abstract: The ^{6}Li(p, α)^{3}He reaction has been studied with proton energies from 1.0 to 2.6 MeV. The excitation curve and angular distributions were measured by a coincidence method. The results showed that the absolute cross sections for this reaction are lower in this energy region than earlier measurements.

E | NUCLEAR REACTION ^{6}Li(p, α), E = 1.0–2.6 MeV; measured $\sigma(E, \theta)$, $\sigma(E)$. Coincidence method. Enriched target.

1. Introduction

Nuclear chain reactions for light nuclei ($A < 10$) involving only charged particles are important at the present time in studies of controlled thermonuclear reactors [1]. For a ^{6}Li-d fueled fusion reactor, the ^{6}Li(p, α)^{3}He reaction is of particular interest. The absolute cross sections for this reaction as a function of bombarding proton energy have been summarized in fig. 14 of ref. [1]). Of particular importance are the cross sections in the neighborhood of the 1.85 MeV resonance which corresponds to a $J = \frac{5}{2}^-$, p-wave state around 7.8 MeV excitation in ^{7}Be [ref. [2])]. The calculation of the ^{6}Li(p, α)^{3}He reaction rate [3]) is quite sensitive to the magnitudes of the cross sections in the neighborhood of the resonance and more complete experimental data in this region would clearly be useful for evaluations of the contribution of the ^{6}Li(p, α)^{3}He reaction to the reactivity of a closed d-^{6}Li plasma.

Since there were considerable deviations between different cross-section measurements for proton energy below 3 MeV [refs. [2,4])], it is worthwhile to present accurate data in this particular energy range. Although measurements of absolute cross sections involve relatively simple apparatus and trivial calculations, actual experiments involve the determination of many elusive quantities. A precision of better than 10 % for an absolute cross section is generally difficult to attain. Previous works measured the reaction particles directly using conventional electronics, so that pile-ups due to elastic scattering caused severe background problems which led to large errors in cross-section determination. We have for the first time used a coincidence method in the present experiment to take the data. It is expected that clean spectra with almost no backgrounds could be obtained by this method. Furthermore, most of the targets used in the previous works were prepared by evaporating ^{6}Li metal onto a backing and then allowing them to remain in air for sufficient time in order to obtain the stable hydroxide. The uncertainty in the chemical composition in this kind of targets was also very large. The discrepancies in the published absolute cross sections emphasize the need for new measurements of these cross sections. In this paper we present accurate results on the ^{6}Li(p, α)^{3}He reaction from 1 to 2.6 MeV.

2. Experimental method

The ^{6}Li(p, α)^{3}He reaction was studied with proton energies from 1 to 2.6 MeV by using the 7 MeV Van de Graaff accelerator at the Institute of Nuclear Energy Research. The proton beam from the accelerator was analysed by a 90° deflecting magnet and regulated to an energy spread of less than 2 keV. The beam spot on the target in a scattering chamber was about 2 mm in diameter. The detectors used were 500 μm silicon surface barrier detectors. They were mounted in two movable arms and could be rotated around the central axis of the scattering chamber. Coincidence measurements were taken with these two detectors for chosen angle pairs. A Faraday cup and current integrator monitored the proton beam. Typical beam currents were about 30 nA. The targets used were prepared by evaporating the lithium fluoride enriched to 96.03 % in ^{6}Li onto a carbon backing of about 35 μg/cm^2. The thickness of the ^{6}LiF in the targets was 110 ± 5 μg/cm^2.

Since one could observe at any angle both the ^{3}He and α-particle reaction products, it is only necessary to measure the angular distribution from 0° to 90°. The angular distribution of the α-particle at backward angles could then be deduced using the kinematics of the reaction from the angular distribution of ^{3}He at forward angles. In the energy region studied, elastically scattered protons and α-particles from the reaction ^{19}F(p, α)^{16}O would normally interfere with the ^{3}He and α-particles for the ^{6}Li(p, α)^{3}He reaction at most angles. A coincidence method has been used to remove this undesired background. Each of the two ^{3}He and α signals at any forward angle was in time coincidence with the other signal at a kinematically determined backward angle. The two signals from each detector were fed to a coincidence circuit, the output of which was then used to gate the linear signals from the detector at the forward angle. The signals were finally analysed in a Hewlett-Packard 4096-channel pulse-height analyzer. Two circular apertures in front of the detector at forward angles defined an angular acceptance of about 1° and subtended a solid angle of 0.146 msr at the target center. The solid angle of the detector at backward angles was defined such that it accepted both of the coincidence particles. In order to make sure of this fact, singles spectra and coincidence spectra were measured independently at some angles where peaks due to the ^{3}He could be separated clearly from others. It was found that the numbers of counts of the two measurements were in good agreement within statistical errors. A schematic diagram of the electronics is shown in fig. 1.

The cross sections were measured from 1.0 to 2.6 MeV proton energy at angles from 20° to 90° in the lab system in steps of 10°. The energy steps used were from 50 keV

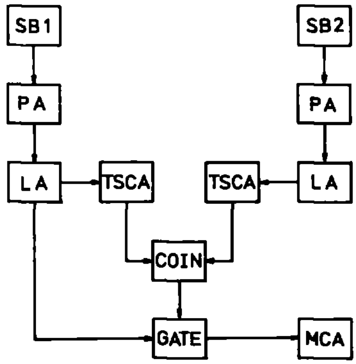

Fig. 1. Block diagram of electronics: SB, surface-barrier detector; PA, preamplifier; LA, linear amplifier; TSCA, timing single channel analyser; COIN, coincidence; GATE, linear gate; MCA, multi-channel analyser.

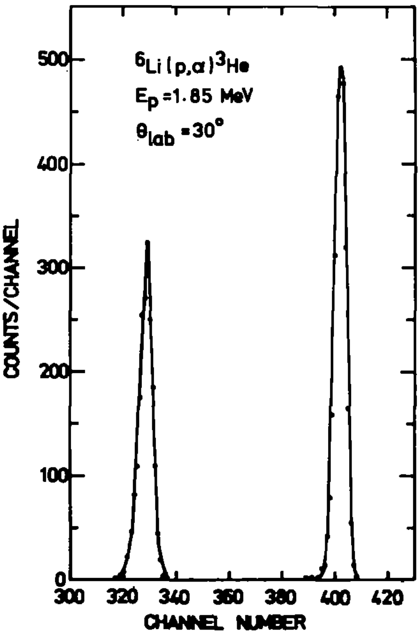

Fig. 2. The ^{3}He and α-particle spectrum obtained at 30° for the ^{6}Li(p, α)^{3}He reaction at 1.85 MeV bombarding energy.

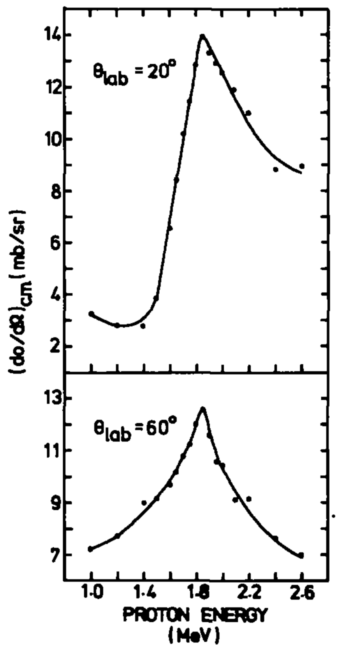

Fig. 3. Excitation curves of the α-particles from the ^{6}Li(p, α)^{3}He reaction at θ_{lab} = 20° and 60°.

in the neighborhood of the 1.85 MeV resonance to 200 keV at the low and high limits of the energy region studied. The target thickness was checked repeatedly during the runs by a monitor fixed at 90°. Fluctuations in the thickness were observed, but were less than 8 %. The variations were presumably due to nonuniformity in the target. Fig. 2 shows a typical spectrum of the reaction particles at 1.85 MeV and $\theta_{lab} = 30°$.

3. Results and discussion

The absolute differential cross section is calculated directly from the known solid angle, target thickness and number of incident protons. Fig. 3 shows the excitation curves for the α-particles obtained at $\theta_{lab} = 20°$ and 60°. They are very similar to those obtained by Marion *et al.* [2]). The resonance is clearly seen at 1.85 MeV from these curves. The angular distributions in the c.m. system were fitted to the equation

$$\frac{d\sigma}{d\Omega}(\theta) = A_0[1 + \sum_{n=1} A_n P_n(\cos\theta)],$$

by the method of least squares on CDC-6600 computer. Here $P_n(\cos\theta)$ is the Legendre

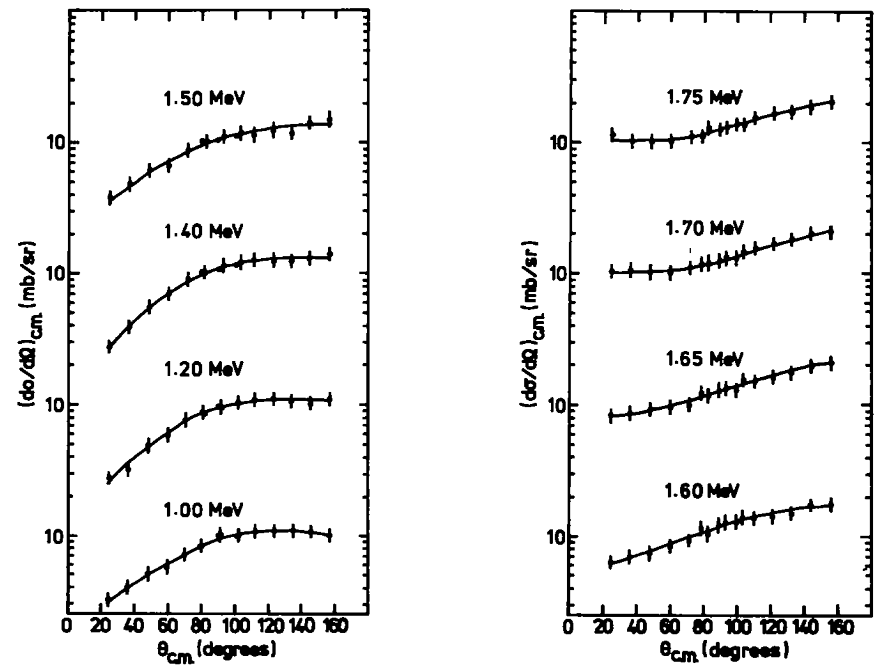

Fig. 4a. Angular distributions of α-particles from the $^6Li(p, \alpha)^3He$ reaction for various incident proton energies. The closed circles show points measured from observations of the α-particle and the open circles the points obtained from observations of the recoil ^3He. The error bars indicate the absolute errors. The curves are best fit to the data with Legendre polynomials.

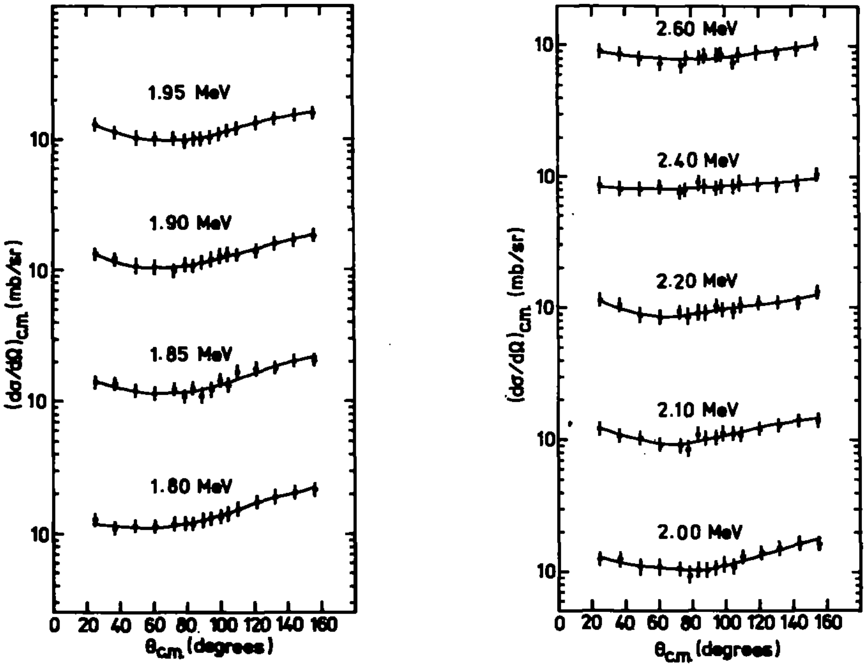

Fig. 4b. See caption to fig. 4a.

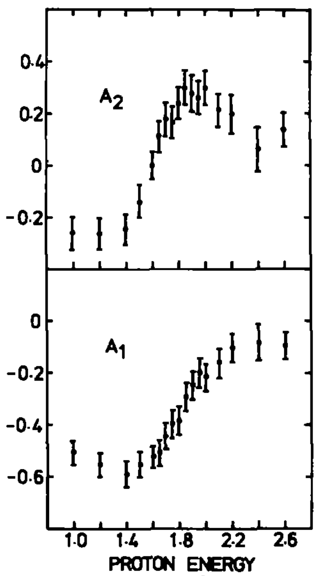

Fig. 5. Variation of A_1 and A_2 coefficients with incident proton energy.

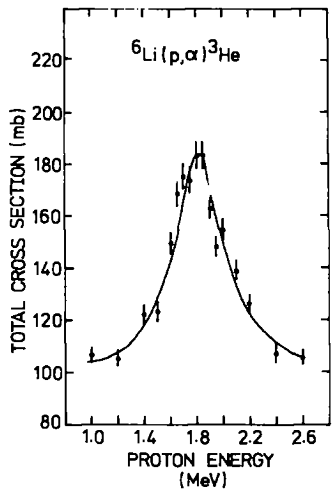

Fig. 6. Total cross section as a function of incident proton energy. The error bars indicate absolute errors. The curve is a guide to the eye.

polynomial of order n. The total cross section was extracted from the zero-order coefficients of these fits ($\sigma_T = 4\pi A_0$).

The shapes of the angular distributions vary smoothly over the bombarding energy range studied, as can be seen in figs. 4a and b. The error bar includes the statistical errors (< 3 %), the uncertainty in target thickness (estimated to be about 8 %), the errors in current integrator calibration (4 %) and in solid angle measurements (3 %). Therefore, the absolute differential cross sections are accurate to about 10 %. The coefficients of order greater than two in the polynomial expansions were essentially zero within errors, and thus including higher order polynomials made no significant difference to the extracted total cross sections. Fig. 5 shows the A_1 and A_2 coefficients defined above, as functions of the proton energies. The odd-order coefficients are clearly nonzero in the energy range shown, indicating the presence of interference between levels of the opposite party. This has been noted in a number of previous studies, e.g. ref. [5]), but so far no positive parity states have been definitely identified in ^7Be.

The total cross section and its uncertainty as a function of incident proton energy is shown in fig. 6 and given in table 1. The uncertainty at a given proton energy is deduced from the least squares fit to the angular distribution data at this energy.

TABLE 1

Total cross section and its uncertainty for the $^6Li(p, \alpha)^3He$ reaction

E_p (MeV)	σ_T (mb)	$\Delta\sigma_T$ (mb)	E_p (MeV)	σ_T (mb)	$\Delta\sigma_T$ (mb)
1.00	107	3.36	1.85	184	5.44
1.20	105	3.35	1.90	163	4.67
1.40	123	4.05	1.95	148	4.36
1.50	123	3.93	2.00	155	4.60
1.60	150	4.45	2.10	140	4.07
1.65	169	5.06	2.20	127	3.68
1.70	176	5.13	2.40	108	4.11
1.75	174	5.05	2.60	106	3.03
1.80	183	5.30			

The shapes of the angular distributions of the α-particles shown in figs. 4a and b are very similar to those published by Marion *et al.* [2]). The absolute differential cross section obtained at E_p = 1.4 MeV and θ_{lab} = 90° (12 ± 1.5 mb/sr) is very near to the result given by Lerner *et al.* [6]) at E_p = 1.36 MeV and θ_{lab} = 90° (10.9 ± 1.4 mb/sr).

The absolute total cross section shown in fig. 6 has a prominant resonance at 1.85 MeV. The shape of the resonance is much more symmetric and its width more narrow (≈ 500 keV) than those obtained by Marion *et al.* [2]). The background is almost constant over this energy range. The magnitude of the total cross section at the lower energy side (≈ 1 MeV) of the resonance is about 16 % and that at the higher energy side (≈ 2.6 MeV) is about 40% lower than the results obtained by previous workers. When the background is subtracted from the total cross section the magnitude at the resonance peak is about 20% lower than those published previously.

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