MEASUREMENT OF DIFFERENTIAL CROSS-SECTIONS OF THE ^{6}Li(n,t)^{4}He REACTION*

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Abstract

Differential cross-sections and angle integrated cross-sections of the ^{6}Li(n,t)^{4}He reaction were measured at 1.05, 1.54 and 2.25 MeV by using a gridded ionization chamber. Neutrons were produced through the T(p,n)^{3}He reaction on the 4.5 MV Van de Graaff at Peking University. The absolute neutron flux for 2.25 MeV was determined by the ^{238}U(n,f) reaction, and for 1.54 and 1.05 MeV by a calibrated BF$_3$ long counter. Present results are compared with existing data.

1. Introduction

^{6}Li(n, t)^{4}He reaction data are important in nuclear science and engineering. Although the cross-section of this reaction is accepted as a neutron cross-section standard from 0.0253 eV to 100 keV, there are big discrepancies among the existing data (including experimental and evaluated ones) in the mega-electron-volt neutron energy region. Therefore, new measurements are needed to clarify discrepancies. In our previous works, measurement of differential cross-section and angle integrated cross-section data for the ^{6}Li(n, t)^{4}He reaction were carried out at E_n=1.85, 2.67, 3.67 and 4.42 MeV by using the gridded ionization chamber (GIC) method [1,2]. In the present work, we extended our experiment to E_n=1.05, 1.54 and 2.25 MeV to study the systematic behavior of this reaction.

2. Experiment

Compared to our previous experiment, the present measurement used a thinner ^{6}LiF sample, and a thinner neutron production target. It was maiden in order to fit for the lower energy neutron induced charged particle measurement. The experiment was performed at the 4.5 MV Van de Graaff accelerator of the Institute of Heavy Ion Physics, Peking University. For each neutron energy point, forward (from 0° to 90°) triton and forward alpha events were measured to get the complete differential data of the ^{6}Li(n,t)^{4}He reaction and to avoid the influence from the thermal neutron induced charged particles. The absolute neutron flux for E_n=2.25 MeV was determined by using a ^{238}U sample back-to-back set with the ^{6}LiF sample inside the GIC.

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However, it is difficult to determine the absolute neutron flux at 1.05 and 1.54 MeV by using the ^{238}U sample, because the fission cross-section is either too small, or change too steep with the neutron energy. Thus a relatively calibrated BF_3 long counter was used as neutron flux monitor for each energy point. Nearly mono-energetic neutrons were produced through the $T(p,n)^3He$ reaction with a solid T-Ti target 0.80 mg/cm^2 in thickness. The energies of the accelerated protons before entering the target were 1.90, 2.37 and 3.07 MeV, and by Monte Carlo calculation the corresponding neutron energies were 1.05 ± 0.09, 1.54 ± 0.08 and 2.25 ± 0.06 MeV, respectively.

The structure of the common-cathode twin-ionization chamber with Frisch-grids and the related electronics were described in [1]. For the present experiment, the electronics was slightly different from [1] in that the common cathode preamplifier connected two linear amplifiers with different gains for $^6Li(n, t)^4He$ event and fission fragment measurement. The working gas of the GIC was Kr+2.11% CO_2. The distances from the cathode to grid, the grid to anode and the anode to shield were 4.3, 2.2 and 1.1 cm, respectively. In order to reduce the interference from the thermal neutron induced $^6Li(n_{th},t)^4He$ reaction, the ionization chamber was coated with a layer of cadmium ~0.5 mm in thickness.

The ^{6}LiF sample was evaporated on a tantalum backing 4.80 cm in diameter, with the ^{6}Li abundance 90.5%. The area and the thickness of the sample were 15.21 cm^2 and 85.5 μg/cm^2, respectively. It was attached to the common cathode at the forward side of the twin GIC. The ^{238}U fission foil (99.999% in purity, 7.85 ± 0.10 mg in weight, 4.50 cm in diameter) was set at the backward side of the GIC, for absolute neutron flux measurement at E_n=2.25 MeV, and for absolute calibration of the BF_3 long counter at 1.54 and 1.05 MeV. Two compound α sources were placed back-to-back on another position of the sample changer of the GIC for energy calibration of the data acquisition system. There was also a tantalum sheet set on the third position of the sample changer at forward side for background measurement. With the sample changer, it is easy to change sample positions without opening the chamber.

For alpha measurement, the pressure of the working gas of the GIC was 4.56×10^4 Pa (0.45 atm) for E_n=1.05 and 1.54 MeV, and 5.88×10^4 Pa (0.58 atm) for 2.25 MeV. At the former working pressure, the voltages for cathode, grid and anode were −500, 0 and +450 V, respectively, and at the latter working pressure, the voltages were −650, 0 and +580 V for the electrodes.

Fig. 1 is the cathode-anode two-dimensional spectrum for forward alpha measurement at E_n=2.25 MeV.

For triton measurement the gas pressure was 2.33×10^5 Pa (2.30 atm) for 1.05 MeV, and 3.19×10^5 Pa (3.15 atm) for 1.54 and 2.25 MeV. At the former working pressure, the voltages for cathode, grid and anode were −2600, 0 and +2300 V, respectively, and at the latter working pressure, the voltages were −3500, 0 and +3000 V for the electrodes.

Fig. 2 shows the two-dimensional spectrum for forward triton measurement (E_n=2.25 MeV). As seen in this figure, triton events in large angles (near 90°) overlap with alpha events but the interference is only confined in the region near the 90° line because of the high gas pressure. For alpha measurement there was no such problem because the triton energy loss in the sensitivity volume is very small compared to alpha energy due to the low gas pressure.

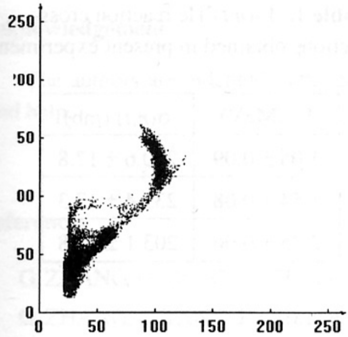

Fig.1. The two-dimensional spectrum for forward α measurement at E_n=2.25 MeV

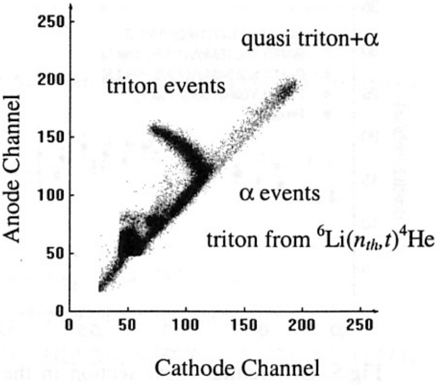

Fig.2. The two-dimensional spectrum for forward triton measurement at E_n=2.25 MeV

The center of the GIC was placed at 0° to the beam line, and the distance from its cathode to the neutron target was 18.8 cm. The BF_3 long counter was placed at 0° to the beam line 2.9 m from the T-Ti target. The proton beam current was ~ 10 μA during experiment. The total beam time was ~31 to 45 h for each neutron energy. The background in the region of interest was very sparse compared to the events. The cross section data of the ^{238}U(n, f) reactions were taken from the ENDF/B-VI library.

3. Results

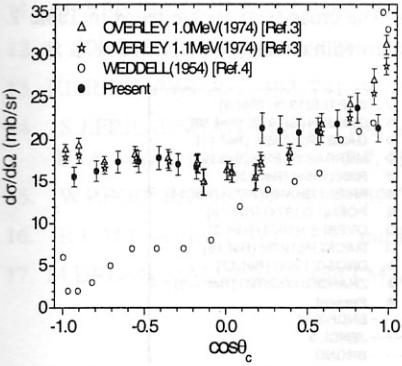

Fig.3. Differential cross sections in the c.m. system for the ^{6}Li(n,t)^{4}He reaction at 1.05 MeV compared with existing data

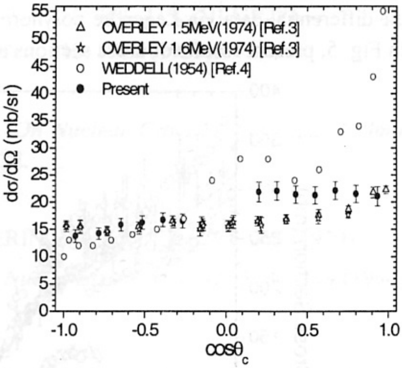

Fig.4. Differential cross section in the c.m. system for the ^{6}Li(n,t)^{4}He reaction at 1.54 MeV compared with existing data

Fig. 3÷5 show the measured differential cross-sections transferred to the center-of-mass (c.m.) system at 1.05, 1.54 and 2.25 MeV, respectively. Present differential cross-sections are compared with existing data [3-7].

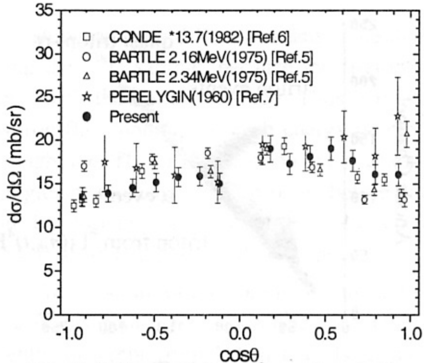

Fig.5. Differential cross section in the c.m. system for the ^{6}Li(n,t)^{4}He reaction at 2.25 MeV compared with existing data

Table 1. ^{6}Li(n,t)^{4}He reaction cross-sections obtained in present experiment

E_n (MeV)	$\sigma(n,t)$ (mb)
1.05 ± 0.09	240.6 ± 17.8
1.54 ± 0.08	233.4 ± 17.3
2.25 ± 0.06	203.1 ± 13.8

Backward triton data were obtained by translating the forward alpha data. In dealing with forward triton or alpha data, the region in the two-dimensional spectrum near 90° line ($\cos\theta_L$=0÷0.3) was excluded because of alpha interference and the absorption effect in the sample. Thus, the particle leaking problem [8] can be avoided at E_n=1.05 MeV, and can be neglected at E_n=1.54 and 2.25 MeV. Principal sources of error include neutron flux determination (5.5÷7.0%), statistics for α–particle or triton counts (2.1÷3.0%), and background subtraction, normalization, and particle leaking effect (3.5%).

Angle integrated cross-sections for the ^{6}Li(n, t)^{4}He reaction were derived from the differential data via Legendre polynomial fitting. The cross-sections are listed in Table 1. In Fig. 5, present results of cross sections are compared with existing data [1-3, 9-17].

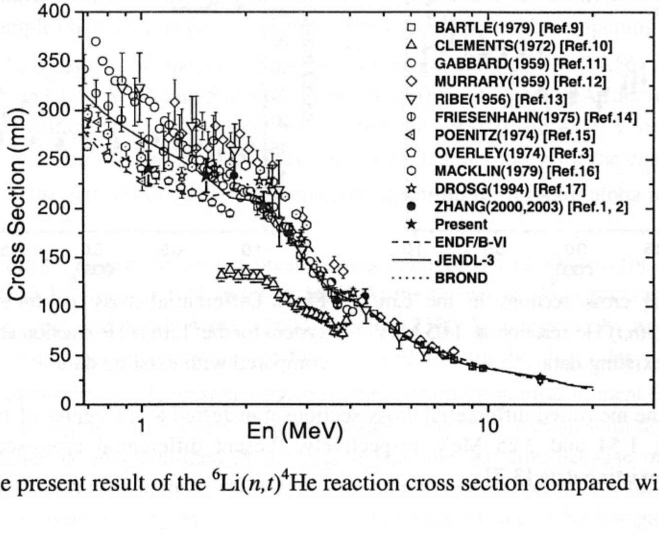

Fig. 6 The present result of the ^{6}Li(n,t)^{4}He reaction cross section compared with existing data

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References

1. G. ZHANG, G. TANG, J. CHEN et al., *Nucl. Sci. Eng.*, **134**, 312 (2000).
2. G. ZHANG, G. TANG, J. CHEN et al., *Nucl. Sci. Eng.*, **143**, 86 (2003).
3. J. C. OVERLEY, R. M. SEALOCK, and D. H. EHLERS, *Nucl. Phy. A,* **221**, 573 (1974).
4. J. B. WEDDELL and J.H.ROBERTS, *Phy. Rev.*, **95**, 117 (1954).
5. C.M. BARTLE, *Proc. 4th Conf. On Nuclear Cross-Sections and Technology*, USA, Washington D.C., Mar. 3-7, 1975, p. 688.
6. H. CONDE et al., *Proc. Int. Conf. On Nuclear Data for Science and Technology*, Belgium, Antwerp, Sep. 6-10 1982, p.447, Dr. Reidel Publishing Company (1983).
7. V. P. PERELYGIN and K. D. TOLSTOV, *Soviet Atomic Energy,* **9**, 1028 (1961).
8. G. GIORGINIS, and V. KHRIATCHKOV, *Nucl. Instrum. Methods,* A **538**, 550 (2005).
9. C.M.BARTLE, *Nucl. Phys.*, A **330**, 1 (1979).
10. P.J.CLEMENTS et al., EANDC(UK)-141, 1972.
11. F.GABBARD, R.H.DAVIS, and T.W.BONNER, *Phys. Rev.*, **114**, 201 (1959).
12. R.B.MURRARY and H.W.SCHMITT, *Phys. Rev.*, **115**, 1707 (1959).
13. F.L.RIBE, *Phys. Rev.*, **103**, 741 (1956).
14. S.J.FRIESENHAHN et al., *Proc. 4th Conf. On Nuclear Cross-Sections and Technology*, USA, Washington D.C., Mar. 3-7, 1975, p. 232.
15. W.P.POENITZ, *Z. Phys.*, **268**, 359 (1974).
16. R.L.MACKLIN, R.W.INGLE, and J.HALPERIN, *Nucl. Sci. Eng.*, **71**, 205 (1979).
17. M.DROSG, D.M.DRAKE, and J.MASARIK, *Nucl. Instrum. Methods*, B **94**, 319 (1994).