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Differential Cross Section Measurements for the ^{6}Li(n,t)α Reaction in the Few MeV Region

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Abstract. New measured differential cross sections of tritons and alpha particles following the ^{6}Li(n,t)α reaction are reported for incident neutron energies between 0.2 and approximately 20 MeV. The neutrons were produced by spallation at the WNR facility at the Los Alamos Neutron Science CEnter (LANSCE), with the incident neutron energy determined by the time-of-flight method. Four E-ΔE telescopes were used at eight laboratory angles. These data have been incorporated into a prior R-matrix fit for the compound ^{7}Li system, and result in an (n,t) reaction cross section that is 4% to 10% higher than previous evaluations in the 1-3 MeV incident neutron energy region.

Keywords: ^{6}Li(n,t) differential cross section, R-matrix.
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INTRODUCTION

The ^{6}Li(n,α)t reaction is widely used in neutron detection and other applications due to its positive Q-value, and its cross section is well measured and is considered a standard at low neutron energies (from thermal to about 10 keV). In the few MeV incident-neutron energy range, despite a large number of measurements, this cross section is considered to be uncertain by as much as 20%, as a result of discrepant measurements and the cumulative effect of nearby resonances. A series of recent measurements of both the reaction cross section and the angular distribution of the products at discrete incident neutron energies from 1.05 to 4.42 MeV have been reported [1-3], using the gridded ionization chamber technique to detect the reaction products [4]. These new measurements are generally consistent with the prior data, though with some discrepancies, and overall they suggest that in the 1 to 2.5 MeV energy range that the ENDF/B-VI evaluation somewhat overestimates the reaction cross section. Recently, theoretical analyses using the R-matrix [5] have been performed. The authors suggest that uncertainties about the interferences between the three resonances near 2 MeV give rise to too large uncertainties in the fitted cross section of this reaction in the few MeV region. As a result, new measurements were again suggested as a way to resolve these issues.

Differential cross section measurements provide information on the nature of the resonances in the compound system, in this case ^{7}Li. In this paper we address these issues with new triton and α particle angular distribution measurements performed with a “white” spectrum of neutrons. We have previously reported a preliminary set of data from this project [6]; this report includes additional data and conclusions drawn from the complete data set.

THE EXPERIMENT

The neutron beam was produced by spallation following the bombardment of a tungsten target by 800 MeV protons at the Weapons Neutron Research facility (WNR) [7] of the Los Alamos Neutron Science CEnter (LANSCE). The experiments were conducted using a scattering chamber located at 15.3 m on a flight path at 30 degrees relative to the proton beam. The beam structure consisted of micropulses of protons separated by 1.8 or 3.6 μs. The neutron beam was monitored with a ^{235}U fission chamber [8]. The incident neutron energy was determined using the time-of-flight technique, corrected for the time-of-flight of the reaction product detected.

The reaction products were detected by four three-stage particle telescopes, which were variously positioned at eight scattering angles during the experiment. Each telescope consisted of a gas ΔE detector, followed by a Si detector, and finally by a CsI detector. The gas used in the ΔE detectors was approximately 20 torr of P-10. The Si detectors were manufactured by AMETEK (ORTEC) and were 500 μm thick. The CsI detectors were not used in the data analysis for this experiment. Details of this apparatus can be found in S. Grimes, et al.[9] and in ref. [6].

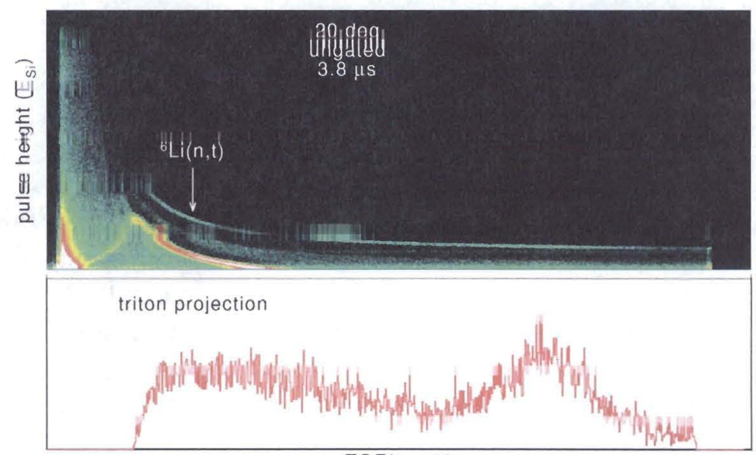

FIGURE 1. Si detector pulse height spectrum as a function of TOF with a 3.8 μs proton-beam micropulse spacing. The tritons from the ^{6}Li(n,α)t reaction are clearly visible in the 2d spectrum, and the projection of the tritons onto the TOF axis is shown in the lower panel. The low incident neutron energy (high TOF) peak visible toward the right side of the triton projection is the first resonance in this reaction at 240 keV.

The targets were composed of LiF, with the Li enriched to 95.5% ^{6}Li, evaporated onto a thin mylar backing. The mylar backing thicknesses and uniformity were determined by α particle energy loss measurements and analysis using the energy loss code SRIM[10]. The LiF uniformity was determined in the same way, while the thickness of the ^{6}Li was measured directly by assaying the amount of Li on each target by MS-ICP, following the dissolution of the LiF in HF acid, after the completion of the measurements described in this paper. Separately, the isotopic enrichment of the LiF was determined by a TOF-SIMS measurement of the ^{6}Li to ^{7}Li ratio in the target material, confirming the expected enrichment. The Si detector energy and efficiency calibrations were done with a ^{229}Th source. α particles were clearly distinguished from hydrogen isotopes by E-ΔE gating with the particle telescopes.

Figure 1 shows the ungated time-of-flight versus Si pulse height spectra, with the tritons and alpha particles from the $^{6}Li(n,\alpha)t$ reaction identified. These spectra were taken with a LANSCE/WNR micropulse spacing of 3.6 μs, meaning that the LANSCE 800 MeV proton beam struck the WNR neutron production target every 3.6 μs (during each "macropulse" of beam, of which there were 40 per second lasting typically 625 μs each; data were not taken between macropulses). The prominent first resonance in the $^{6}Li(n,\alpha)t$ reaction at 240 keV is clearly visible in the triton-gated TOF projection (lower panel). Triton yields were obtained as a function of the incident neutron energy from spectra similar to that seen in Fig. 1, and α particle yields were obtained from such spectra following α-particle-gating.

THE RESULTS

Triton differential cross section data from the $^{6}Li(n,t)\alpha$ reaction were taken for incident neutron energies between 0.18 and 12 MeV for eight laboratory angles. Figure 2 shows these results for four of these angles as excitation functions, compared to R-matrix fits up to 4 MeV. These new data are consistent with a more pronounced resonance structure at 2 MeV than the prior evaluations. The data below the 240 keV resonance is systematically low compared to the prior evaluation. While this feature is not understood, we note that this is also the part of the spectrum for which "wrap-around" and attenuation corrections are the largest in our data analysis.

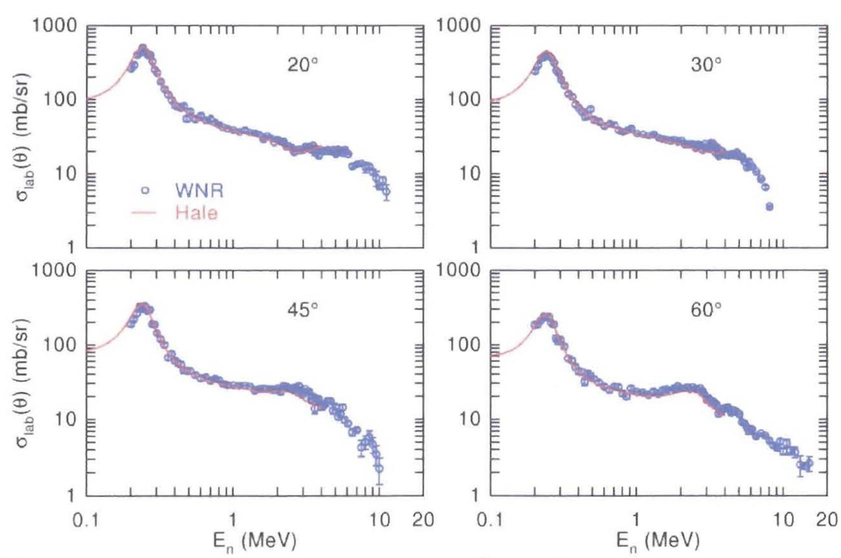

FIGURE 2. Excitation functions for tritons from the $^{6}Li(n,\alpha)t$ reaction at four of the eight angles measured, as a function of incident neutron energy. The line is the result of an R-matrix calculation including the current data (see ref. [5]).

Differential cross section data was also obtained for the α particles from the same reaction for five laboratory angles over a range of incident neutron energies from 1 to 20 MeV. The reduced angular range, relative to the triton data, and the lack of data at lower incident neutron energies, was due to energy loss effects in the targets. Figure 3 shows the α particle excitation functions for four of the five angles. Since other reaction channels open up with increasing energy – notably the triton breakup reaction, the (n,α) cross section is larger than the (n,t) cross section above incident neutron energies of a few MeV.

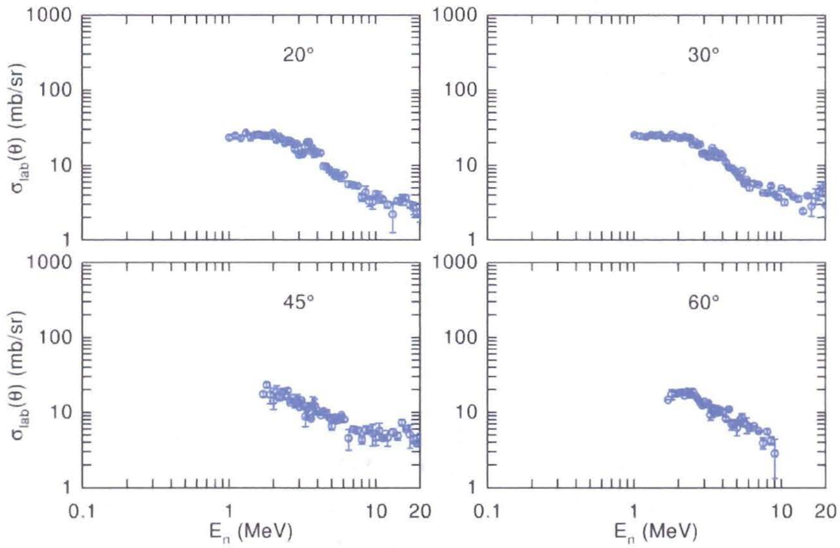

FIGURE 3. Excitation functions for α particles from the ^{6}Li(n,α)t reaction at four of the five angles measured, as a function of incident neutron energy

These new data have been added to the existing R-matrix calculation of the compound ^{7}Li system, which at present extends up to an incident neutron energy of 4 MeV. The resulting ^{6}Li(n,t) reaction cross section is shown in Fig. 4, compared to the data of R.L. Macklin, et al.[12], and M. Drosg, et al.[13], and to the prior ENDF/B-VII and ENDL evaluations. The impact of the more pronounced resonance structure at 2 MeV in the new data is evident in the inset of Fig. 4: The new R-matrix fit is 8.8% above the ENDL evaluation, and approximately 4.5% higher than the ENDF/B-VII evaluation at 2 MeV. An evaluation of the impact of the new data on the ^{6}Li(n,t) and ^{6}Li(n,α) reactions above 4 MeV is in progress.

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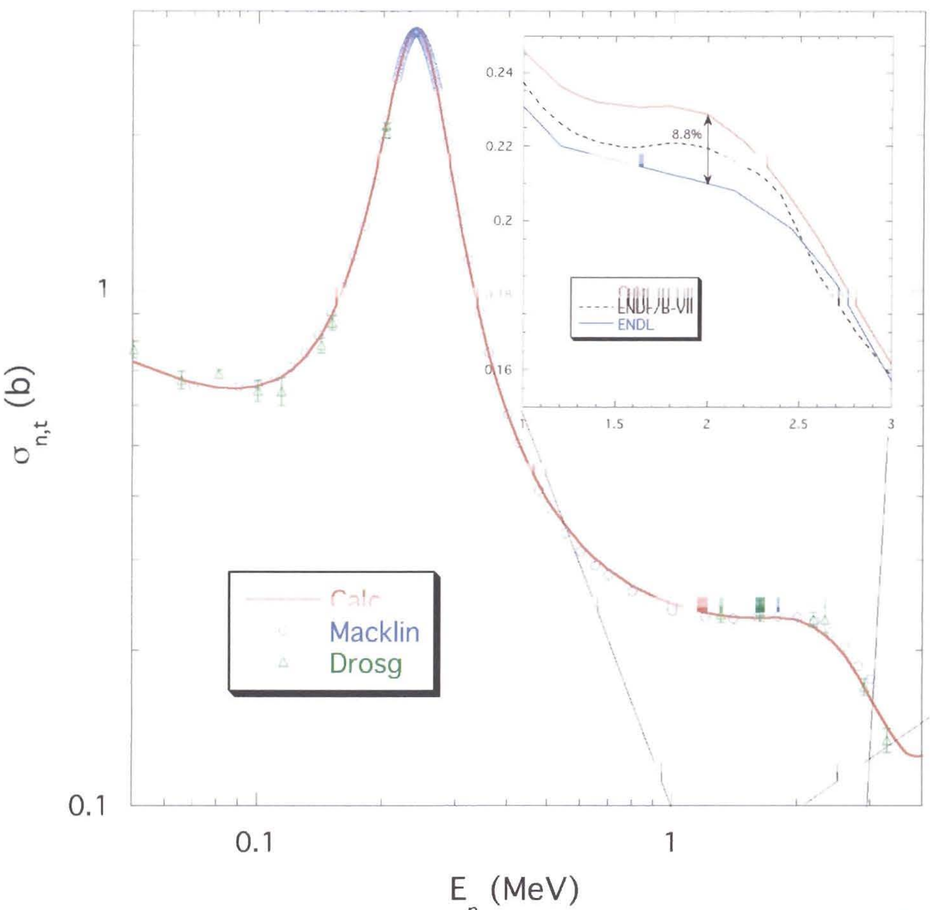

FIGURE 4. The total ^{6}Li(n,α)t cross section, as determined in by an R-matrix calculation including the new differential cross section data ("Calc"), compared to the data of R.L. Macklin, et al.[12], and M. Drosg, et al.[13], and to the prior ENDF/B-VII and ENDL evaluations.

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