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Measurement of angle-dependent differential cross sections of $^{2}H(t,n)^{4}He$ with triton energies from 5.97 to 16.41 MeV

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Abstract

As a spin-off of an $^{3}H(t,n)$ experiment not only double-differential neutron break-up spectra of the reaction $^{2}H(t,n)$ became available but also angle-dependent differential cross sections of $^{2}H(t,n)^{4}He$. These were determined at 5.97, 7.47, 10.45, and 16.41 MeV, at no fewer than 8 angles between 0 and 145 degrees with a scale uncertainty of less than 2%. As no independent data are available for this reaction, no direct comparison with data by other authors was feasible. Thus, they are compared with data obtained from the evaluation of the $^{3}H(d,n)^{4}He$ reaction.

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Abstract--As a spin-off of an $^{3}H(t,n)$ experiment not only double-differential neutron break-up spectra of the reaction $^{2}H(t,n)$ became available but also angle-dependent differential cross sections of $^{2}H(t,n)^{4}He$. These were determined at 5.97, 7.47, 10.45, and 16.41 MeV, at no fewer than 8 angles between 0 and 145 degrees with a scale uncertainty of less than 2%. As no independent data are available for this reaction, no direct comparison with data by other authors was feasible. Thus, they are compared with data obtained from the evaluation of the $^{3}H(d,n)^{4}He$ reaction.

I. INTRODUCTION

The sparsity of experimental cross section data of the $^{2}H(t,n)^{4}He$ reaction[1-2] makes any data of this reaction particularly interesting even if such cross sections have been available already for some time by means of an elaborate evaluation of the $^{3}H(d,n)^{4}He$ cross sections[3]. The twin reaction $^{3}H(d,n)^{4}He$ has at the corresponding angles the same center-of-mass cross sections as $^{2}H(t,n)^{4}He$ with a projectile energy reduced by a factor 0.6680.

Like the double-differential break-up data published some time ago[4] the present data are a spin-off of a $^{3}H(t,n)$ experiment[5]. This fact explains why the experiment was not optimized to isolate t-D differential two-body cross sections.

II. EXPERIMENT

The experiment was performed at the HVEC tandem accelerator of the former Ion Beam Facility (IBF) at Los Alamos National Laboratory, using a time-of-flight system with a 2" × 2" liquid scintillator (NE213) as a neutron detector having a detection threshold of 0.29 MeV equivalent proton energy. Standard gas targets[6-7] of 3.0 cm length with an entrance foil of 5.3 mg/cm^{2} molybdenum and a beam-stop made of gold (0.076 cm thick) were used. The areal density of the deuterium gas was 0.21 mg/cm^{2} except for the data at 16.41 MeV where it was 0.13 mg/cm^{2}. The digital recorder of the gas pressure (about 0.2 MPa) allowed readings with a resolution of about 0.2%. At four triton energies, namely 5.97, 7.47, 10.45, and 16.41 MeV, angular distributions were measured typically at 0°, 15°, 30°, 60°, 90°, 120°, and 145°. For this purpose the heavily shielded detector was rotated around a pivot situated under the center of the gas target. The distance between the center of the gas target and the center of the detector was 3.53 m, the total time resolution was 2.1 ns (FWHM of the prompt gamma-ray peak). The emission angles were measured with a resolution of 0.1 degree. By means of the strong angle dependence of the $^{1}H(t,n)^{3}He$ neutron yield the actual 0 degree position was determined to be (0.30 ± 0.05) degrees by measuring at the same nominal angle left and right.

The isotopic abundance of deuterium in the gas (the contamination with hydrogen) was determined in situ by determining the ratio of the areas of the two-body peak from $^{1}H(t,n)^{3}He$ in hydrogen and deuterium gas. **Table I** shows these ratios for the individual gas fillings at the four energies. It was found to be on the order of 1% at all energies. Due to the repeated filling of the cell with hydrogen, the contamination with hydrogen is expected to increase in the course of the experiment.

TABLE I

Experimentally determined impurities of the deuterium fillings.

Triton energy	Hydrogen admixture
16.41 MeV	1.2%
10.45 MeV	0.6%
7.47 MeV	1.0%
5.98 MeV	0.4%

The energy dependence of the efficiency of the neutron detector was determined point-wise[6-7] by (1) measuring neutron yields of the reactions $^{2}H(t,n)^{4}He$ and $^{1}H(t,n)^{3}He$ at about 30 neutron energies between 2.2 and 36.9 MeV, and (2) comparing them with the well-known cross sections[3].

III. DATA REDUCTION, AND RESULTS

Table II gives the new cross sections at the four energies. In graphical form they are shown in **Figs. 1** through **4**. A discussion of the uncertainty contributions is found in **Table III**. The numerical values of the present differential cross sections will be available in the EXFOR[8] library of the International Network of Nuclear Reaction Data Centers.

A well-designed experiment to measure the angle dependence of the t-D differential cross sections in the 10 MeV region requires special measures to be optimum. E.g. at 16.41 MeV the neutron energy drops from 34 MeV at 0 degrees to 10 MeV at 145 degrees. The high energy at 0 degrees asks for an excellent time resolution of the system combined with a long flight-path so that the energy resolution is adequate when using the time-of-flight technique. The wide energy span requires that the energy dependence of the neutron detection efficiency (the efficiency curve) is reliably known over this wide energy span.

In the present case, where the data are just a side product of another experiment, there was no optimization of the fight path. Consequently, it was not always straightforward to isolate reliably the two-body neutron peak in the spectrum. However, the energy tilt of the efficiency curve was well under control. With a noticeable tilt in the efficiency curve, measuring the angular dependence of the same c.m. cross sections via the d-T and the t-D reactions would not give the same answers, as the tilt in the two cases has opposite effect. Thus, it was assured that the tilt in the efficiency curve was less than 1% per 10 MeV neutron energy.

TABLE II

Angle-dependent $^{2}\mathrm{H}(t,n)^{4}\mathrm{He}$ laboratory differential cross sections at four projectile energies. Angles Θ in degrees, differential cross sections σ and their uncertainties $\Delta\sigma$ in mb/sr. These uncertainties do not include the scale uncertainty.

5.97 MeV			**7.47 MeV**			**10.45 MeV**			**16.41 MeV**		
θ	**σ**	**Δσ**	**θ**	**σ**	**Δσ**	**θ**	**σ**	**Δσ**	**θ**	**σ**	**Δσ**
0.1	11.94	0.29	0.1	11.67	0.39	0.1	10.14	0.20	0.0	13.39	0.81
14.9	11.52	0.19	14.9	11.60	0.24	15.2	10.01	0.17	15.0	10.18	0.41
29.9	9.99	0.19	29.9	10.26	0.24	29.9	8.57	0.16	30.0	6.54	0.31
44.9	7.96	0.17							45.2	3.79	0.19
59.9	5.86	0.14	59.9	4.98	0.16	59.9	3.93	0.10	59.9	2.31	0.20
74.9	4.97	0.13	74.9	4.36	0.16	75.4	4.51	0.08	75.2	3.28	0.19
89.9	5.40	0.13	90.0	5.06	0.16	89.9	5.39	0.12	90.0	5.07	0.24
100.1	5.45	0.14				100.0	5.15	0.11			
						110.0	4.39	0.11			
119.9	6.07	0.14	119.9	5.80	0.19				120.0	1.95	0.18
						129.8	4.22	0.11			
144.9	7.32	0.25	144.9	7.71	0.32	144.9	5.97	0.20	144.9	3.45	0.31

Table III

Uncertainty components

SCALE UNCERTAINTY	
Accuracy of reference cross section	1.5%
Adjustment uncertainty	<1%
Total scale uncertainty	<1.8%
INDIVIDUAL UNCERTAINTIES	
Mass (“gas pressure”)	0.2%
Statistical uncertainties	included in data table
Random background subtraction uncertainty	included in data table
Systematic background subtraction uncertainty	included in data table
Energy dependence of efficiency	included in data table
Dead-time correction	<0.3%, disregarded
PARAMETER UNCERTAINTIES	
Triton energy	≤0.03 MeV
Scattering angle	0.1°
Detector opening angle (geometry effect)	at 0° half-opening angle <0.3°, not corrected

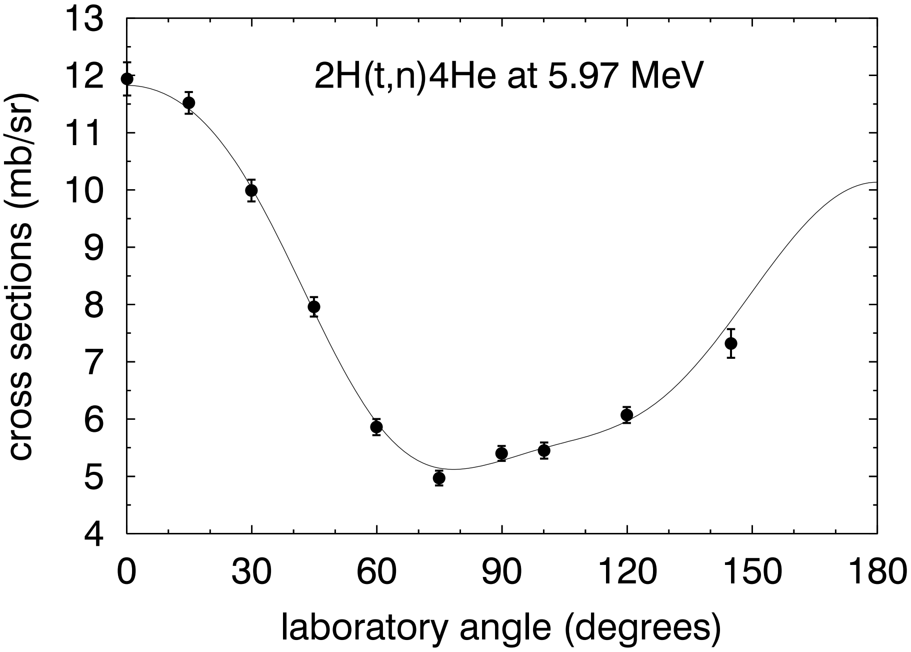

Fig. 1. Angle dependent differential laboratory cross sections of $^2H(t,n)^4He$ at 5.97 MeV triton energy. New data vs. cross section predictions[2] (full line)

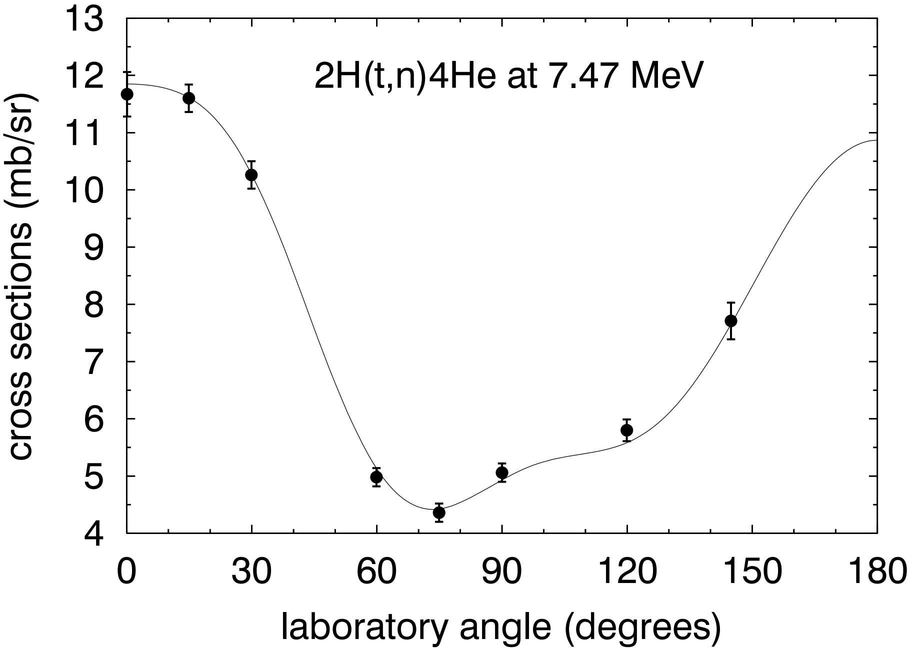

Fig. 2. Angle dependent differential laboratory cross sections of $^2H(t,n)^4He$ at 7.47 MeV triton energy. New data vs. cross section predictions[2] (full line)

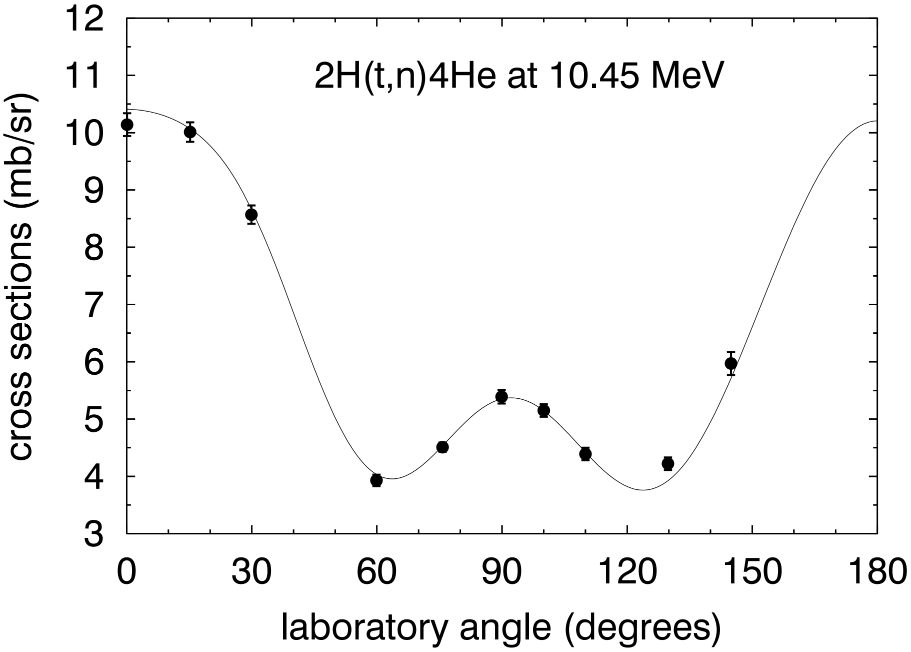

Fig. 3. Angle dependent differential laboratory cross sections of ^{2}H(t,n)^{4}He at 10.45 MeV triton energy. New data vs. cross section predictions[2] (full line)

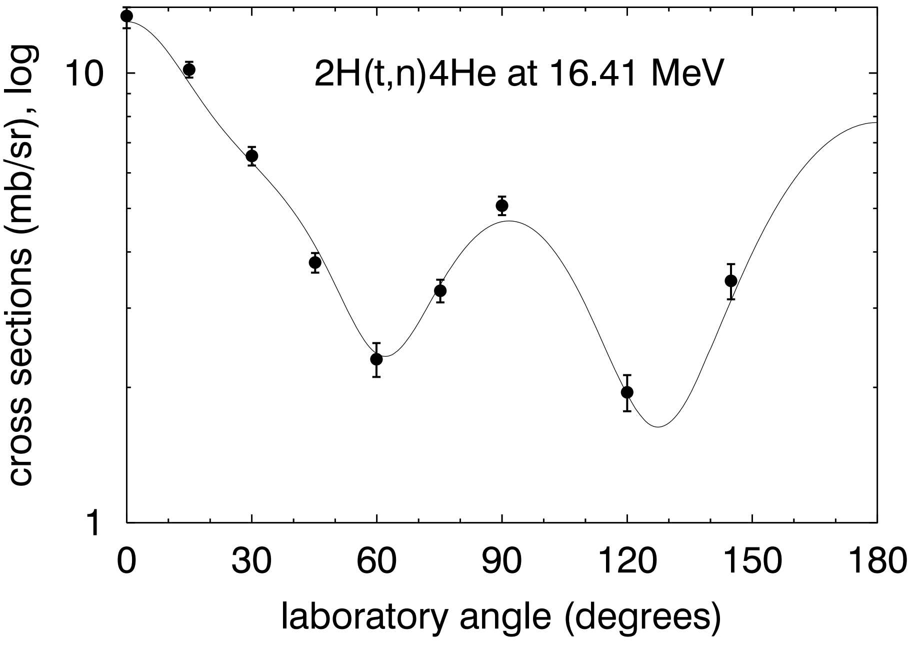

Fig. 4. Angle dependent differential laboratory cross sections of ^{2}H(t,n)^{4}He at 16.41 MeV triton energy. New data vs. cross section predictions[2] (full line)

Another parameter that is of some importance is the target thickness. The present data at 16.41 MeV suffer from a reduced target thickness, resulting in increased uncertainties.

The main defect of the present data is that their scale was not determined independently. Thus, they are relative data. However, they are given as absolute cross sections. Their scale was determined by fitting the distributions to the predictions of the ^{3}H(d,n)^{4}He evaluation[3]. Thus, it should not surprise that in Figs. 1 through 4 there is no obvious scale discrepancy between the data points and the curve.

IV. DISCUSSION

The t-D data at 5.97, 7.47, and 10.45 MeV were shown already in graphical form as center-of-mass cross section of ^{3}H(d,n)^{4}He at a conference[2]. The present data values supersede these data. Although the measured data are identical and the method of data reduction did not change, the scale uncertainty could be decreased from 3 to 2% due to the improved evaluation of the d-T data[3] to which the scale is connected.

Figs. 1 through 4 are a near perfect corroboration of the shape of the data as obtained from the ^{3}H(d,n)^{4}He evaluation[3] which is mirrored in the data bank ENDF[9]. However, as can be seen from **Fig. 5** some questions concerning the back-angle data of ^{3}H(d,n)^{4}He remain open. The high experimental data point at 7 MeV (Drosg 1995) remains unexplained. Less obvious is the fact that the point at 16.41 MeV is high, even if within uncertainty bar. The suspicion that the evaluated curve is low is further fed by the fact that also the 15 degrees data point is even more pronounced high (10.18±0.41 vs. 9.50 mb/sr). Furthermore, the value at 16.65 MeV (Drosg 1978) is also somewhat high.

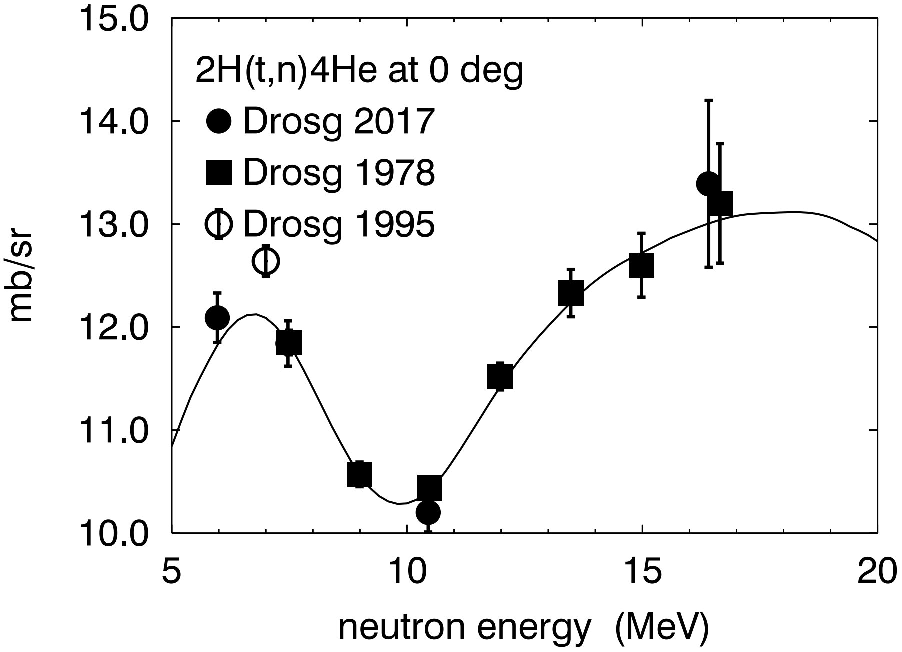

Fig. 5. 0-deg excitation laboratory function of ^{2}H(t,n)^{4}He. All available data are compared with the cross section predictions of Ref. 3 (full line)

As it is very unlikely that in the future experimental data will clarify the situation there is some hope that an R-matrix analysis will help although the energy is somewhat high (11 MeV in the d-T system).

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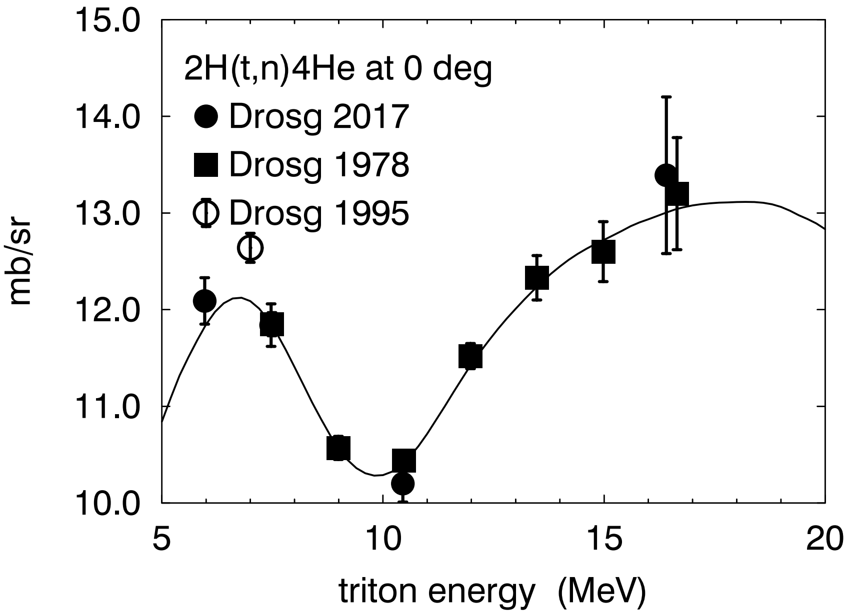
2H(t,n)4He at 0 deg
● Drosg 2017
■ Drosg 1978
○ Drosg 1995
mb/sr
15.0
14.0
13.0
12.0
11.0
10.0
5
10
15
20
triton energy (MeV)