

D(d,n)³He Differential Cross Sections from 18 to 26 MeV

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Abstract

Angular distributions of the D(d,n)³He reaction have been measured for incident deuteron energies of 18, 20, 22, 24 and 26 MeV. The data provide no evidence for the proposed broad level in ⁴He at approximately 30 MeV.

Introduction

The D(d,n)³He reaction is frequently employed as a neutron source. For example, Bartle *et al.* (1977) used this reaction in conjunction with associated particle techniques to produce a flux of monoenergetic neutrons with energies of up to 20 MeV for a maximum incident deuteron energy of 26 MeV. Differential cross section data for the D(d,n)³He reaction for deuterons in the energy range 18-26 MeV are required to optimize the neutron yield in such applications. However, the single measurement of Van Oers and Brockman (1963) at 25.3 MeV provides the only data above 18 MeV. The present work sought to establish the differential cross sections for the energy range 18-26 MeV.

In addition, the D(d,n)³He differential cross section is of interest in this energy range because of a proposed 2⁺ bound state in ⁴He. Werntz and Meyerhof (1968), from an *R*-matrix analysis of differential cross sections and neutron polarization in the ³H(p,n)³He reaction, proposed such a level at approximately 30 MeV. More recently, Erdas *et al.* (1970) predicted from cross section calculations for the ⁴He(γ,d)d reaction, using the dispersive approach of Bosco (1961) with corrections for the interaction between the outgoing deuterons, that a 2⁺ level should be located at 30 MeV; later (Erdas *et al.* 1971) the estimate of the excitation energy was revised to 33 MeV with a reduced width γ² of 5 MeV, which would correspond to an observed width of 25 MeV for the present system. The present incident energy range of 18-26 MeV corresponds to excitation energies in ⁴He of between 32.85 and 36.85 MeV. Thus it was hoped that the measurements might provide additional information about the proposed level.

Experimental Procedure

A 3 mg cm⁻² self-supporting deuterated polyethylene target (Bartle 1977) was bombarded with a deuteron beam from the ANU cyclotron injector and EN tandem

accelerator system. Beam currents ranging from 10 to 30 nA were used, the current being varied in order to maintain an essentially constant ^3He count rate of approximately $150 \text{ counts s}^{-1}$ as the detector angle was varied.

The ^3He recoils were measured with a silicon surface barrier detector telescope as used by Bartle *et al.* (1977). The telescope consisted of an ' E_1 - E_2 -veto' configuration using detectors of thickness 30, 490 and $100 \mu\text{m}$ respectively. The detector telescope was mounted on a rotating platform. The transmitted beam was measured in a Faraday cup mounted 339 cm from the target, and a $2000 \mu\text{m}$ silicon surface barrier detector, fixed at approximately 35° to the transmitted beam direction, monitored the target yield. The experimental arrangement is shown schematically in Fig. 1.

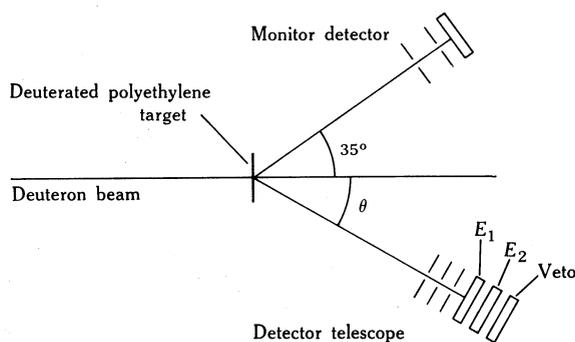


Fig. 1. Schematic diagram of the experimental set-up. The detector telescope consisted of 30, 490 and $100 \mu\text{m}$ silicon surface barrier detectors. The acceptance angle of the collimator block was 0.44° in the horizontal plane and 1.76° in the vertical plane.

The detector telescope was mounted behind a collimator housing which contained three rectangular collimators and electron suppression magnets. The full angle subtended by the slit system was 0.44° in the horizontal plane (the plane of the experiment) and 1.76° in the vertical plane, corresponding to a solid angle of 0.24 msr . The collimator block for the monitor detector subtended angles of 0.44° in the horizontal plane and 2.26° in the vertical plane.

At each of incident deuteron energies of 18, 20, 22, 24 and 26 MeV, the ^3He yield was measured from 7° to 35° in the laboratory system in 15 steps, corresponding to a range of approximately 17.5° to 95° in the centre of mass system. The detector signals were analysed using a particle identification system (England 1973) to produce a total energy spectrum (Fig. 2a) and a spectrum proportional to ' mz^2 ' (Fig. 2b). The mz^2 spectrum showed the ^3He and the ^4He groups distinctly separated. The two spectra were recorded in event mode enabling projections to be made of either spectrum with a window on the other, and thus allowing accurate determination of the ^3He yield.

There is some contamination of the ^3He spectrum due to the $^{12}\text{C}(d, ^3\text{He})^{11}\text{B}$ reaction. It can be seen from the kinematics shown in Fig. 3 that the ^3He energy from the $\text{D}(d, n)^3\text{He}$ reaction is greater than that from the $^{12}\text{C}(d, ^3\text{He})^{11}\text{B}$ reaction for all but the largest angles measured. Thus at these angles the peak of interest

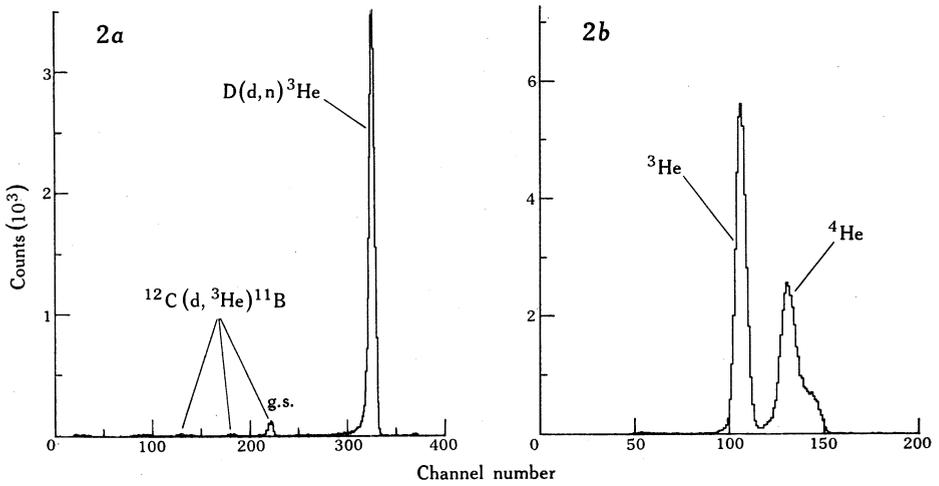


Fig. 2 (above). Projection of the total energy spectrum (a) and a window on the ³He peak of the *mz*² spectrum (b), for the D(d, n)³He reaction with an incident deuteron energy here of 26 MeV and a laboratory scattering angle of 22.5°.

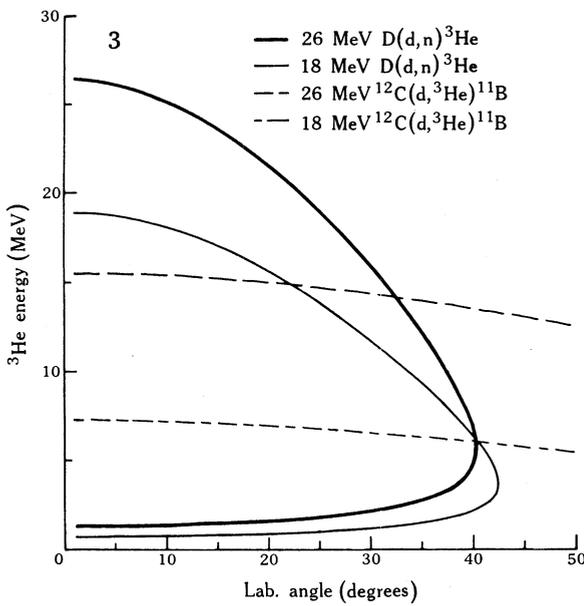


Fig. 3 (left). Plots of the ³He energies for the reactions D(d, n)³He and ¹²C(d, ³He)¹¹B at 18 and 26 MeV.

will be superimposed on ³He peaks from the ¹²C(d, ³He)¹¹B reaction; the magnitude of the contamination was accurately estimated by means of measurements with a carbon target.

It should also be noted that for any particular angle and bombarding energy in the range being considered, the D(d, n)³He reaction produces two different ³He energies. Only the higher energy group was detected here.

Results

The angular distributions were obtained by normalizing the ³He yield from the detector telescope particle identification system to the yield from the fixed monitor detector. Normalization of distributions at consecutive energies was performed by

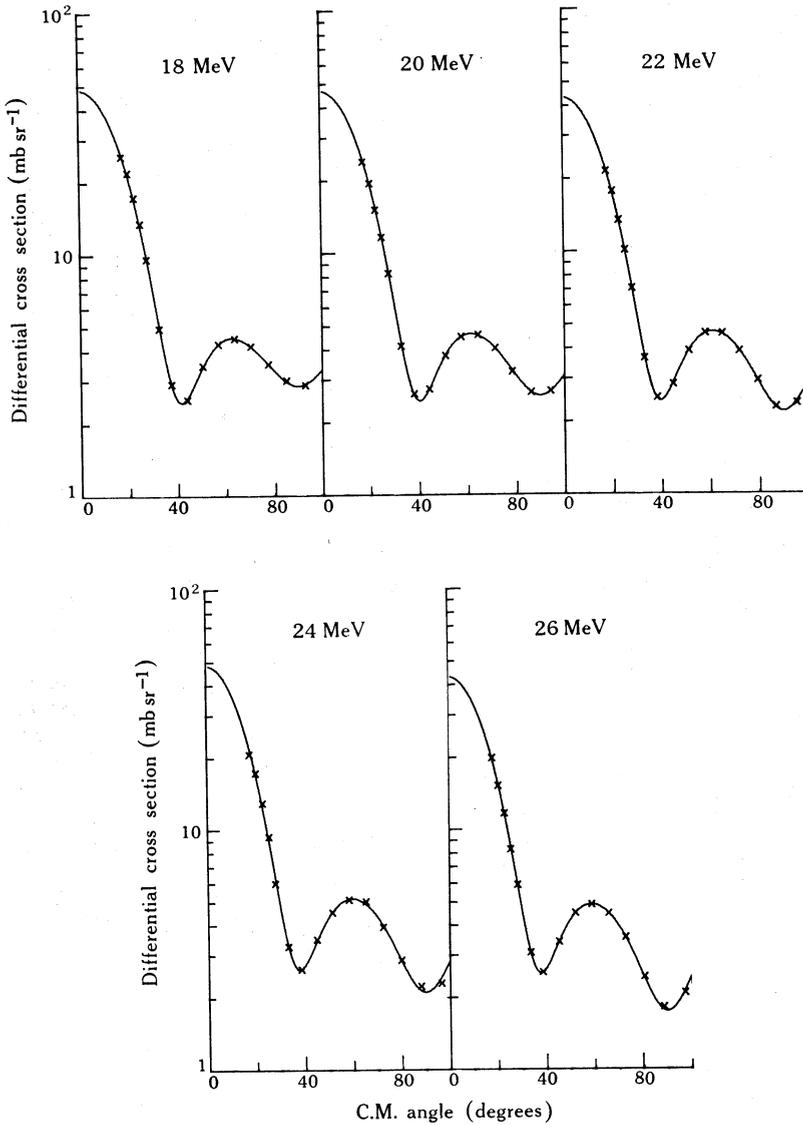


Fig. 4. Legendre polynomial fits (curves) to the measured differential cross sections for $D(d, n)^3\text{He}$ at the five deuteron energies studied.

comparing the ratios of the monitor yield to the total collected charge at the end of the measurement at each energy and the beginning of the measurement at the next energy. The results obtained are plotted in Fig. 4. The 18 MeV data were normalized to the results of Dietrich *et al.* (1972) to provide absolute cross sections.

Even-order Legendre polynomials of the form

$$(d\sigma/d\Omega)_{\text{cm}} = \sum_{n=0}^{n_{\text{max}}} A_{2n} P_{2n}(\cos \theta)$$

Table 1. Legendre polynomial coefficients for least squares fits to c.m. angular distributions from D(d, n)³He

Coefficient	Deuteron energy (MeV) for angular distribution				
	18	20	22	24	26
A_0	6.12 ± 0.03	5.87 ± 0.03	5.54 ± 0.03	5.73 ± 0.03	5.30 ± 0.03
A_2/A_0	1.78 ± 0.01	1.72 ± 0.01	1.65 ± 0.02	1.59 ± 0.02	1.63 ± 0.02
A_4/A_0	2.26 ± 0.02	2.14 ± 0.02	2.00 ± 0.02	1.85 ± 0.03	1.80 ± 0.03
A_6/A_0	2.08 ± 0.02	2.18 ± 0.03	2.22 ± 0.03	2.32 ± 0.03	2.34 ± 0.03
A_8/A_0	0.67 ± 0.02	0.78 ± 0.03	0.78 ± 0.03	0.93 ± 0.03	0.94 ± 0.03
A_{10}/A_0	0.11 ± 0.02	0.16 ± 0.02	0.19 ± 0.02	0.27 ± 0.02	0.25 ± 0.03
A_{12}/A_0	—	—	—	0.06 ± 0.03	0.03 ± 0.03

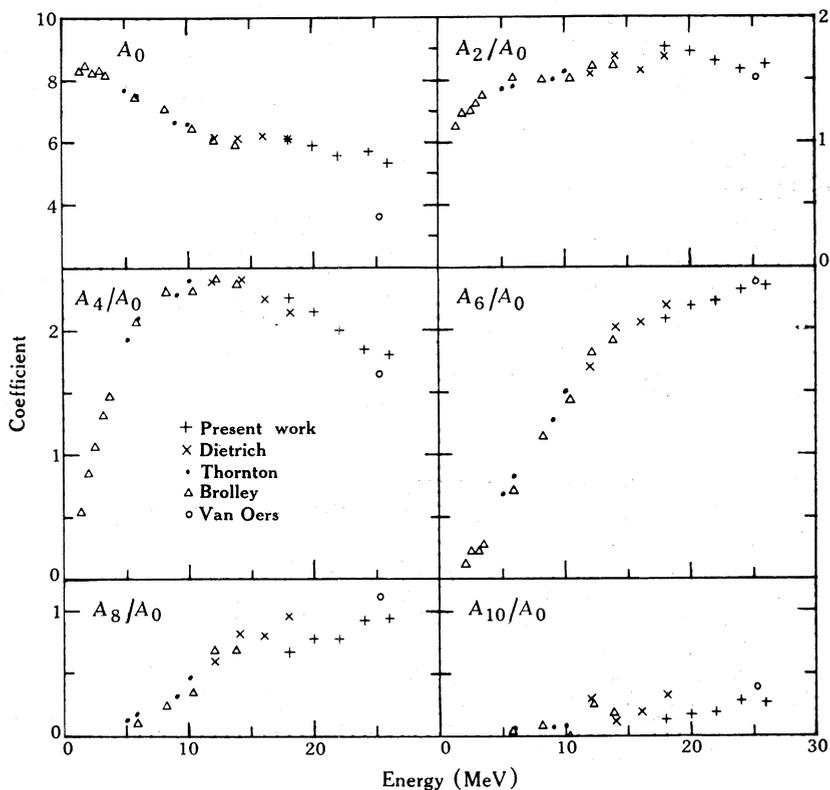


Fig. 5. Zeroth order Legendre polynomial coefficients and normalized higher order coefficients from the present work compared with the results from previous work (Brolley *et al.* 1957; Van Oers and Brockman 1963; Thornton 1969; Dietrich *et al.* 1972).

were least squares fitted to the angular distributions (Table 1). Only even-order Legendre polynomials are required because the distributions are symmetric about 90°(c.m.) as a consequence of the identical nature of the incident and target particles. It was possible that contaminants may have caused the breakthrough of odd-order polynomials, but because of the good fit achieved using only even-order polynomials and the absence of data above 90°(c.m.), it was not considered beneficial to fit them.

The errors assigned to the data points for the purpose of the fit were the statistical uncertainties plus the uncertainty due to the error in the scattering angle, which was taken to be $\pm 0.1^\circ$. The uncertainty in the cross sections due to this error depends on the slope of the angular distributions. The extreme limit was $\pm 1.4\%$ at the highest energy and steepest slope. The errors given to the coefficients in Table 1 are the least squares fitting errors. When the inclusion of the highest order coefficient gave little or no improvement in the fit, the expansion was terminated. It was found that order 10 was sufficient for energies 18, 20 and 22 MeV and order 12 for energies 24 and 26 MeV.

Fig. 5 shows a plot of the A_0 coefficients and the normalized coefficients A_L/A_0 . The coefficients follow the trends indicated by the lower energy data and thus further analysis, as performed by Dietrich *et al.* (1972), would not yield further information. The absence of any striking features attributable to the proposed resonance does not disprove the existence of the level for two reasons. Firstly, the broad nature of the proposed resonance, which was predicted to have a reduced width of 5 MeV and therefore a much wider experimental width, may be obscuring the effect. Secondly, the $D(d, n)^3\text{He}$ reaction may be a predominantly direct reaction, thus not yielding information about the ^4He system.

It should be noted that the data taken by Van Oers and Brockman (1963), who measured the differential cross sections for the $D(d, n)^3\text{He}$ reaction at 25.3 MeV, have an absolute value approximately 40% lower than the value one would expect from the present data normalized to the work of Dietrich *et al.* (1972). Van Oers and Brockman did not fit Legendre polynomials to their data and so such a fit has been made here using the same procedure as for the present data. The discrepancy is readily seen in the plot of A_0 in Fig. 5.

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