Angular dependence of neutron polarization for the ^{2}H(d,n)^{3}He reaction for deuteron energies less than 500 keV

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The angular dependence of the polarization of the neutrons from the reaction ^{2}H(d,n)^{3}He has been determined for 290 keV and 460 keV incident deuterons. These polarization distributions differ in the 30° to 50° lab region from the previous measurement in this energy region and are discussed in relation to both the low energy theory of the reaction and the approach cross-section description.

[NUCLEAR REACTIONS ^{2}H(d,n), E = 290, 460 keV; measured polarization $P(\theta)$.]

The low energy theory of the ^{2}H-^{2}H reactions developed for deuteron energies up to about 200 keV by Boersma[1] and by Fick and Weiss[2] has been shown by Sikkema and Steendam[3] and by Alsoraya and Galloway[4] to give a satisfactory consistent description of the energy dependence of the neutron polarization and of the differential cross section for the ^{2}H(d,n)^{3}He reaction up to 275 keV deuteron energy. Neutron polarization data for higher deuteron energies (about 1–4 MeV) have been discussed by Purser, Morgan, and Walter[5] and by Galloway, Hall, Maayouf, and Vass[6] in terms of the approach cross-section description of the reaction developed by Beiduk, Pruett, and Konopinski (BPK).[7] In both of these discussions the angular dependence of the neutron polarization measured for 350 keV incident deuterons by Boersma, Jonker, Nijenhuis, and van Hall[8] is of particular importance (Fig. 3). The 1–4 MeV data can be reasonably well fitted within the BPK[7] theory assuming central and tensor forces only to be significant, whereas if the 350 keV data have also to be fitted, a significant spin-orbit interaction must be included. The 350 keV data[8] provide the only thin target measurement of the angular dependence of the neutron polarization for an incident deuteron energy less than 870 keV, and the distinction between the fits with and without the spin-orbit interaction is most marked around 500 keV deuteron energy. Unfortunately, it is reported by Walter[9] that the published 350 keV neutron polarization data[8] require correction for instrumental asymmetries, and certainly the energy dependence measured at the same time[8] differs from the recent measurements.[3,4,10] Thus it was decided to make measurements of the angular dependence of the polarization of the neutrons from the ^{2}H(d,n)^{3}He reaction for deuteron energies of about 300 and 500 keV, an energy region which should be of value in relation to models of the reaction and where reliable data on the angular dependence are lacking.

The reaction was induced by a magnetically analyzed deuteron beam from a 500 keV Van de Graaff accelerator incident on a water cooled Ti-^{2}H target. The neutron polarization was determined from the asymmetry in scattering through 120° by ^{4}He in the same way as previous polarization measurements in this laboratory.[4,6,10,11]

The polarization values determined for a mean deuteron energy of 290 keV and target thickness 105 keV and for a mean deuteron energy of 460 keV and target thickness 95 keV are listed in Table I. They are compared with the 350 keV values of Boersma *et al.*[8] in Fig. 1 and incline to larger magnitudes in the region 30° to 50°. The present values are plotted as a function of center of mass angle in Fig. 2 from which it can be seen that the values define curves which pass through zero at 90° center of mass as is to be expected from the identity of the incident and target nuclei. It can also be seen that the recent polarization values at about 50° center of mass determined by Galloway and Lugo[12] by the very different method of small angle Mott-Schwinger scattering by Pb agree well with the corresponding present values.

Boersma[1] and Fick and Weiss[2] following differ-

TABLE I. Polarization of neutrons from the ^{2}H(d, n)^{3}He reaction.

Lab. angle (deg)	Neutron polarization E_d = 290 keV	E_d = 460 keV
90	0.042 ± 0.011	0.056 ± 0.007
82.5	−0.015 ± 0.008	0.003 ± 0.010
72	−0.088 ± 0.004	−0.094 ± 0.006
58	−0.128 ± 0.006	−0.131 ± 0.007
45	−0.139 ± 0.008	−0.151 ± 0.012
33	−0.118 ± 0.007	−0.117 ± 0.006
24.5	−0.074 ± 0.010	−0.055 ± 0.010

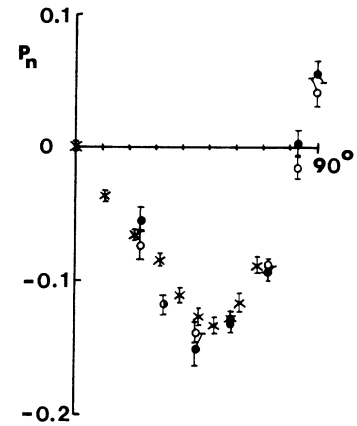

FIG. 1. Comparison of the present neutron polarization values (290 keV deuteron energy, open circles; 460 keV, solid circles) with the values of Boersma *et al.* (Ref. 8) for 350 keV deuterons (crosses).

ent theoretical approaches to the problem deduced the same relationships for the differential cross section and the polarization of the neutrons from the ^{2}H$(d,n)^3$He reaction for energies such that only S and P waves are involved. The differential

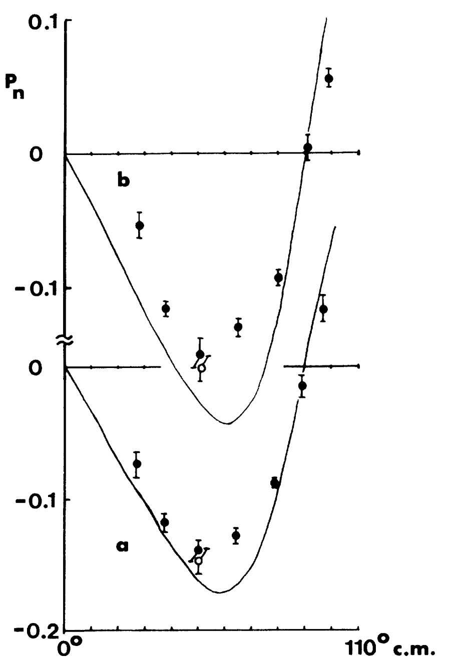

FIG. 2. (a) The dependence of the ^{2}H$(d,n)^3$He neutron polarization on center of mass angle for a mean deuteron energy of 290 keV. Present measurements, solid circles; average of 330 keV and 266 keV values from Ref. 12, open circle; low energy theory (Refs. 1, 2) with parameters from Ref. 4 is shown by the curve. (b) Similarly for the present 460 keV measurements; the open circle indicates the 436 keV value from Ref. 12.

cross section

$$\frac{d\sigma(\theta)}{d\Omega}=A_0+A_2P_2(\cos\theta)\,, \tag{1}$$

the anisotropy coefficient

$$\frac{A_2}{A_0}=\beta\frac{0.05+E_d}{1+\alpha(0.05+E_d)}\,, \tag{2}$$

and the polarization

$$P_n(\theta)=\beta c\frac{(0.05+E_d)P_2^1(\cos\theta)}{1+\alpha(0.05+E_d)+\beta(0.05+E_d)P_2(\cos\theta)}\,, \tag{3}$$

where E_d is the incident deuteron energy and α, β, and c are energy-independent parameters which depend on the transition matrix elements. (β was inadvertently omitted from the right-hand side of Eq. 3 in Ref. 4). Both Boersma[1] and Fick and Weiss[2] assumed the derivation valid for $E_d<200$ keV. Alsoraya and Galloway[4] measured the polarization of the neutrons emitted at 45° for E_d from 35 to 275 keV and showed that a consistent description of the polarization over this energy range and of the available anisotropy coefficients up to 300 keV deuteron energy was provided by $\alpha=3.8$, $\beta=5.0$, and $c=-0.160$. With these values of parameters, Eq. (3) provided the curves in Fig. 2. This low energy description slightly overestimates the magnitude of the polarization at 290 keV, and the discrepancy is larger at 460 keV. Thus by 290 keV the assumption of only S- and P-wave contributions may be an oversimplification.

The differential polarization can be expanded

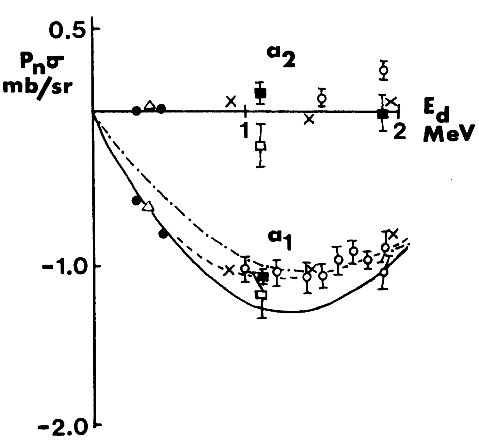

FIG. 3. The differential polarization coefficients a_1 and a_2 for deuteron energies up to 2 MeV. Present measurements, solid circles; Boersma *et al.* (Ref. 8), triangle; Smith and Thornton (Ref. 16), crosses; Galloway *et al.* (Ref. 6), solid squares; Drigo *et al.* (Ref. 17), open squares; Purser, Morgan, and Walter (Ref. 5), open circles. The curves indicate alternative fits to the data based on the approach cross-section description of the reaction (Ref. 7), as described in the text.

$$P_n(\theta)\frac{d\sigma(\theta)}{d\Omega}=\sum_n a_n \sin 2n\theta \qquad (4)$$

in center of mass coordinates[13] or equivalently as a sum of even order associated Legendre polynomials, $\sum_k B_k P_k^1(\cos\theta)$. Such expansions have been used both for the comparison of experimental data and for comparison of data with calculation.[5,6,14] The polarization data of Table I were combined with appropriate differential cross sections,[15] and least squares fits of Eq. (4) yielded for 290 keV $a_1=-0.58\pm0.02$, $a_2=-0.01\pm0.02$, and for 460 keV $a_1=-0.80\pm0.03$, $a_2=-0.01\pm0.02$. These a_1 and a_2 values are compared in Fig. 3 with previous values, all except one pair[8] being at much higher energy. The present a_2 values are in accord with the general trend and need be discussed no further. The present a_1 values suggest that the 350 keV polarization values[8] are indeed too small in magnitude and in need of correction as indicated in the review by Walter.[9]

The curves shown in Fig. 3 for a_1 are those fitted by Purser, Morgan, and Walter[5] to their data and discussed also by Galloway *et al.*[6] They are based on the approach cross-section description of the ^{2}H$(d,n)^3$He reaction by Beiduk, Pruett, and Konopinski.[7] The solid line and the dash-dot line are fits which assume central and tensor forces only and differ in that the 350 keV measurement[8] was taken into account in the fitting procedure which produced the solid line but not in the dash-dot case. The dashed line resulted from a fit which also included a spin-orbit interaction and took account of the 350 keV measurement. The present measurements support a curve similar to the dashed one and so within this picture of the reaction would indicate the need for a spin-orbit interaction.

It is concluded that the low energy *S*- and *P*-wave only description of the ^{2}H$(d,n)^3$He reaction[1,2] found to be acceptable up to about 275 keV deuteron energy[4] can be seen to fail at 290 keV, that the 350 keV neutron polarization values[8] are probably about 10–15% too small, and that the present 290 keV and 460 keV polarization data can be accommodated along with higher energy data[6] within the approach cross-section description of the reaction.[7]

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