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Letters to the Editor

A search for spin dependent effects in the three body final state from the ^{2}H(d, n)pd reaction at 11·3 MeV incident deuteron energy

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Abstract. Cross sections and asymmetries have been measured for the reaction ^{2}H(d, n)pd. Approximate fits to the cross sections have been made using a final state p–d interaction in the Watson–Migdal model.

Deuteron break-up processes provide a profitable field for detailed contact between theory and experiment in the study of the nuclear three-body problem.

Detailed tests of the tensor force can evolve from experiments using polarized projectiles in inelastic processes as has been emphasized by Mitra (1971).

The purpose of the present letter is to present experimental data which show the relevance of spin dependent effects to the break-up cross section for the reaction ^{2}H(d, n)pd at 11·3 MeV incident deuteron energy.

Continuous neutron spectra from the d–D reaction have been studied by Rybakov *et al* (1961), Lefevre *et al* (1962), Donovan (1965), Birchall *et al* (1970) and von Witsch *et al* (1970). There are grounds for belief that departures from phase space exist which may be attributed to final state interactions in the outgoing channels, although the overall situation is confused (McKee 1971).

In order to investigate these effects further it was considered worth while to make measurements of cross sections and asymmetries from 0° to 60° in the laboratory using incident vector polarized deuterons from the radial ridge cyclotron.

The polarized deuteron beam was incident upon a deuterium gas target maintained at four atmospheres pressure. The average beam intensity was one nanoampere at target centre with a mean energy of 11·3 MeV. Neutrons were detected using an NE 213 organic liquid scintillator in conjunction with pulse shape discrimination electronics. Time of flight spectra were recorded by timing detected pulses in relation to the cyclotron radiofrequency pulse using a time to amplitude converter (TAC). A signal from the coincidence between linear pulses and neutron recognition pulses was used to gate the TAC pulse into the multichannel analyser (MCA). Pulses were routed into separate parts of the MCA according to the 'up' or 'down' spin designation of the beam.

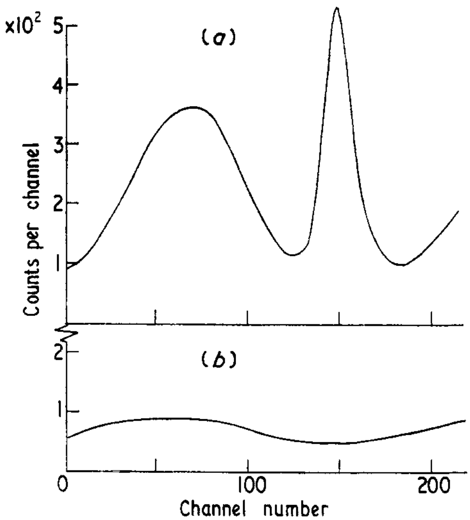

Figure 1. Neutron time of flight spectrum.

Figure 1(*a*) shows a typical time of flight spectrum. The broad peak corresponds to the three-body ^{2}H(d, n)pd neutrons, and the sharp peak corresponds to the two-body ^{2}H(d, n)^{3}He neutrons. The width of the two-body peak gives a direct measure of the timing spread. The lower figure 1(*b*) is a corresponding background spectrum obtained with an evacuated target.

The polarization of the beam was continuously monitored using the ^{12}C(d, p)^{13}C reaction as an analyser. The polarimeter which was situated before the analyser magnet was calibrated by Griffith (1970, private communication), and has an analysing power $iT_{11} = -0{\cdot}693$. The average beam polarization was $\overline{it}_{11} = 0{\cdot}38$.

After unfolding the time spread of the incident beam the time spectra were converted to energy spectra, separated into bins approximately 500 keV wide, and the asymmetries were then calculated between the corresponding 'spin-up' and 'spin-down' spectra. Asymmetries calculated from the unconverted time spectra gave similar values indicating that asymmetries calculated from the energy spectra were not a property of the time unfolding procedure adopted. Figure 2 shows the asymmetries plotted as a function of neutron energy; the errors shown are purely statistical. The asymmetries are small, and in many cases consistent with zero, but the 10°, 20° and 30° data do show a significant trend towards negative values which is largest in the region of high neutron energy.

In order to investigate this effect further it was necessary to evaluate the break-up cross sections and look for evidence for an interaction between particles in the final state. Figure 3 shows the cross sections obtained after removal of the two-body contribution in the regions of overlap between the two- and three-body peaks. The energy spectra were corrected for variation of detector efficiency with energy, and scaled according to the known cross section for the two-body reaction (Thornton 1969). The error bars shown arise from the uncertainty in the value of the neutron energy discriminator. The neutron detector efficiency corrections were calculated using a

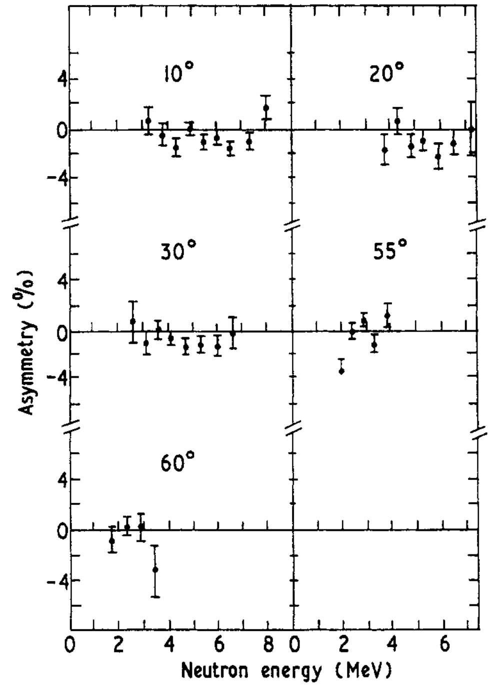

Figure 2. Asymmetries for the ^{2}H(d, n)pd reaction.

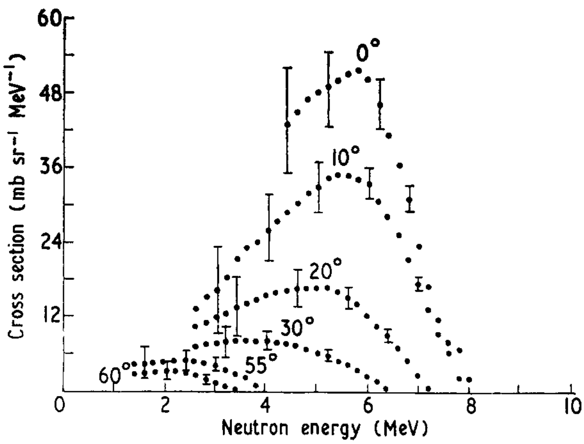

Figure 3. Cross sections for the ^{2}H(d, n)pd reaction.

Monte Carlo method as in Verbinski *et al* (1968). The cross sections obtained are in good agreement with previous measurements (Lefevre *et al* 1962, Birchall *et al* 1970).

Attempts to fit the 10° and 20° data with phase space, after folding in the energy resolution, met with little success. The 30° data alone were reasonably well fitted, but

55° and 60° data were not. Attempts were then made to fit the data using the Watson–Migdal model for final state interactions, inserting into the calculation the known p–d doublet and quartet scattering lengths (van Oers and Brockmann 1967). It is known that the quartet and doublet scattering amplitudes are not mixed by a purely central force, and it is clear from the success of the Amado model (Amado 1969) in interpreting n–d scattering that the central force approximation gives satisfactory results. We therefore treated the contributions from the two channels as incoherent.

It was noted experimentally that the shapes of phase space and the doublet contribution to the scattering cross section were very similar and that the general shape of the 10° and 20° spectra was well reproduced by this calculation. Figure 4 shows the

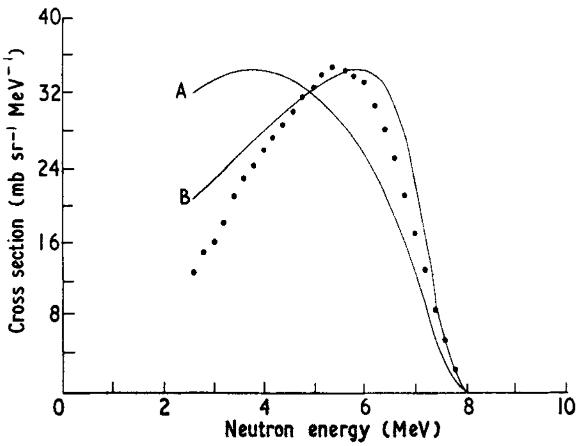

Figure 4. Fits to the ^{2}H(d, n)pd cross section at 10°. • Experiment; A, phase space; B, approximate fit.

10° data; curve A is phase space and curve B is an approximate fit using a quartet scattering length of 11·4 fm. So, approximate fits can be obtained using the Watson–Migdal description, and the angular variation of the ratio of quartet to doublet scattering cross sections does not seem unreasonable, if we use Amado's results as a guide.

The final fits are however only good to about 10% accuracy, so that clearly the nature of the final state interaction is not yet correctly included in the formalism. It may be that some channel spin mixing is taking place in the residual three-nucleon system and causing cross section asymmetries of the kind observed in the present experiment. Recent data from a study of free p–d scattering (Berovic and Clews 1971, private communication) suggest that channel spin mixing is indeed relevant to this interaction. We regard the present measurements as some further evidence for this effect.

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Comments on the theoretical derivation of Wada's and Rao's relations

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Abstract. It is pointed out that the derivation made by Mathur *et al* leading to the relations of Wada and Rao, in effect, employs only the repulsive term of the Lennard–Jones potential. An alternative derivation due to Schuyer, also leading to the relations of Wada and Rao, duly makes use of both terms.

In a recent publication, Mathur *et al* (1971) have derived expressions relating the sound velocity C, density ρ, adiabatic compressibility χ_s and molecular weight M of a liquid, starting from the equation of state

$$p = \frac{kT}{v} - \frac{\partial \phi}{\partial v} \tag{1}$$

where v is the volume per molecule, and

$$\phi = -\alpha v^{-\mu} + \beta v^{-\nu}. \tag{2}$$

From this it follows at once that:

$$\frac{v}{\chi_T} = \frac{v}{\gamma \chi_s} = kT + \beta\nu(\nu+1)v^{-\nu} - \alpha\mu(\mu+1)v^{-\mu} \tag{3}$$

(their equation (5)), where χ_T is the isothermal compressibility and $\gamma = \chi_T/\chi_s = C_P/C_V$. They show that in this expression kT may be neglected, and then proceed to derive a complicated relation between $d\chi_s/dT$ (assuming γ constant) and dv/dT. Integrating this expression again, they find

$$\frac{1}{\chi_s} \propto v^{-\lambda} \qquad \text{that is} \qquad \frac{1}{\chi_s} \propto \rho^{\lambda} \tag{4}$$