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New Measurements of the H(n,n)H Angular Distribution

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Abstract: Measurements have been made of the shape of the hydrogen differential neutron scattering cross section standard at 10 MeV neutron energy. The data were obtained at the Institute of Nuclear and Particle Physics at Ohio University using the D(d,n) reaction as the neutron source. Two different thin films of polypropylene mounted on tantalum backings were used as the hydrogenous samples in this experiment. Preliminary data obtained with the thicker film will be reported here. Two independent computer-based data acquisition systems were used to obtain the data which were stored in a multi-parameter mode so that analysis could be done under different conditions after the experiment was finished. The differential cross section was measured simultaneously at 11 laboratory angles (0°, ± 12°, ± 24°, ± 36°, ± 48° and ± 60°) using ΔE-E solid state detector telescopes in an evacuated scattering chamber. The data are in better agreement with the Arndt evaluation than the ENDF/B-VI and ENDF/B-V evaluations.

Keywords: H(n,n)H standard cross section, n-p angular distribution, neutron cross section standard, D(d,n) reaction, ENDF/B-V, ENDF/B-VI, Arndt

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Introduction

The hydrogen scattering cross section is one of the most important neutron cross section standards. It is often referred to as the primary standard since so many standards are measured relative to it. Almost all measurements of dosimetry cross sections have been made relative to this cross section or a standard which depends strongly on the hydrogen standard. There is a rather large difference between the ENDF/B-V [*1*] and ENDF/B-VI [*2*] evaluations of the hydrogen scattering cross section. The largest

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difference between these evaluations occurs at the most important angle for use of this cross section in neutron fluence monitoring, 180° in the center of mass system which corresponds to proton recoils in a counter telescope at 0° in the laboratory system. There is a maximum difference between the evaluations at this angle of about 2% for a broad energy region centered at about 10 MeV. This is a large difference for a standard which was thought to be very well defined. There has been concern expressed internationally as a result of this rather large difference between the two evaluations. The hydrogen evaluations rely strongly on rather dated measurements. The data are largely clustered around 14 MeV and most of these measurements have uncertainties which are large. The few measurements which have small reported uncertainties [*3, 4*] have led to the pronounced backward peaking of the cross sections in the ENDF/B-VI evaluation. It is important to have new highly accurate hydrogen scattering data to resolve this issue. Also a new evaluation of this cross section [*5*] will begin soon. New measurements could be used directly in that evaluation.

Improved measurements of the very basic interaction of neutrons scattered by hydrogen are also required for a unique description of the nucleon-nucleon interaction. These data are used to refine theoretical calculations and phase shift analyses. The spread in calculated results from such analyses is affected by the limited data base.

To address this problem, the present measurements were made of the shape of the hydrogen differential scattering cross section at 10 MeV neutron energy. The differential cross section can be obtained from these data by normalizing the angle-integrated shape cross section results to the accurately known total elastic cross section. The total elastic cross section is obtained from the total cross section, which is known to 0.2% [*2*], by subtracting the very small neutron capture cross section.

Experimental Details

The measurements were made at 10 MeV neutron energy at the Institute of Nuclear and Particle Physics at Ohio University. This work is a continuation of earlier measurements by this collaboration [*6*]. The new measurements incorporate many changes in the experiment to provide results with smaller systematic errors. Significant improvements were made in the hydrogenous samples, electronics, data acquisition systems and collimators compared with those used in our previous work. A diagram of the experimental setup is shown in Fig. 1.

Neutrons for the experiment were obtained from the D(d,n) neutron source reaction using a 4.2 cm gas target cell maintained at a pressure of 276 kPa (40 psi). A 4.1 μm thick tungsten foil separated the deuterium gas from the accelerator vacuum. A scattering chamber was designed and fabricated especially for this experiment. The relative differential cross section was measured at 11 angles simultaneously with a telescope containing solid state ΔE-E detectors at each angle. This removes problems associated with the very accurate monitoring of the neutron beam intensity which was required with a number of previous experiments for which data were taken one angle at a time. Coincidence measurements between the ΔE and E detectors were made to reduce the background caused by neutrons scattered into the detectors. Measurements were made at 0°, and at equivalent angles on both sides of the neutron beam axis of ± 12°, ± 24°,

± 36°, ± 48° and ± 60° in order to provide consistency checks on the results. These angles, which correspond to the range from 180° to 60° in the center of mass system, check the maximum effect in the ratio of the cross sections, σ(180°)/σ(60°), for ENDF/B-VI compared with ENDF/B-V which is about 3½%.

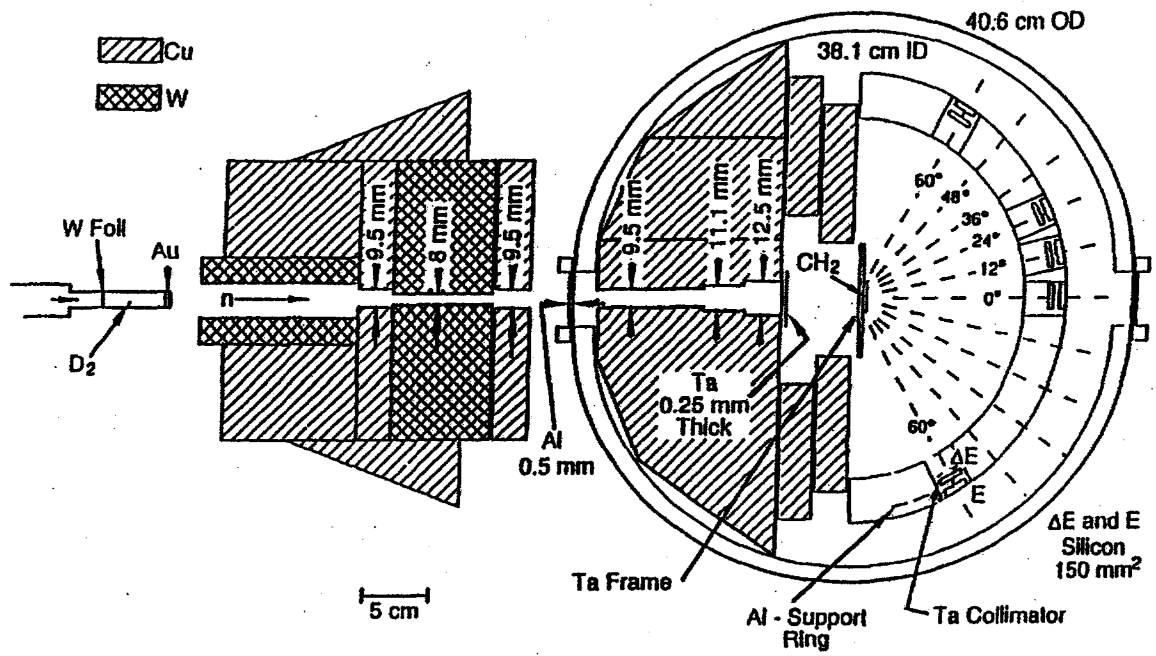

Figure 1. Experimental arrangement for the hydrogen scattering measurement at 10 MeV neutron energy.

Tungsten and copper collimators were used to collimate the neutrons and produce a beam which was approximately uniform over the area of the 1.0 cm diameter hydrogenous sample. A sheet of tantalum covered the collimator to stop charged particles produced in the aluminum entrance window of the chamber and the collimator materials. The collimation also shielded all the detectors, except those at 0°, from the neutron source. Neutron transport calculations were used in the design of the shielding.

For background subtraction, the relative fluence was determined with a stilbene neutron detector located remotely from the scattering chamber near the neutron beam axis.

Corrections have been calculated for multiple scattering in the E detector which can cause protons to be deflected through angles large enough so they are not detected in the E detector. Also the losses from nuclear reactions in the detectors were evaluated. Both of these effects are small, ~ 0.1%.

Thin films of polypropylene were used as the hydrogenous samples in this experiment. In our previous work, the samples were attached to a 1-cm-diameter tantalum collimator with the sample on the side facing the neutron source. This ensured that charged particles produced by neutron interactions in the material used to bond the polypropylene to the tantalum could not get to the detectors, since they would have to pass through the tantalum which is thick enough to stop them. Unfortunately, for this geometry there is a shadowing correction resulting from some proton recoils which are absorbed in the edges of the tantalum collimator. The maximum shadowing correction occurs for the detectors at 60°. Uncertainties in calculations of this quantity led to the use of a different approach. An alternate geometry was used for which a circular film of polypropylene was attached to a tantalum plate (see Fig. 1). The tantalum plate in this geometry is only used as a support, not as a collimator. This allows the surface of the sample to be quite flat. A flat surface is especially important at the larger angles where a wavy film appears like a non-uniform deposit and causes larger energy spread in the recoil protons. With this geometry it is important to minimize the amount of adhesive used to attach the polypropylene to the tantalum plate. This is necessary since charged particles produced by neutron interactions in the adhesive are now not eliminated by a tantalum collimator as was the case for the other geometry. Also it is necessary to produce a uniform layer of adhesive. A complication is that most adhesives do not bond with "normal" polypropylene. The adhesives that do bond tend to produce fairly thick layers. However treated polypropylene film was obtained which has a thin layer of ethylene propylene on one side and a thin layer of ethylene vinyl acetate on the other side. This material could be bonded to tantalum with a very thin layer of ethyl cyanoacrylate. The charged particles produced from neutron interactions with nuclides other than hydrogen in the sample have a negligible effect on the experiment. Two different sample thicknesses were used, 1.4 and 3.8 mg/cm^2 which are referred to as the "thin" and "thick" samples, respectively.

Signals from the electronics were fed to two separate data acquisition systems, each using a separate personal computer. This reduced possible problems with the total counting rate associated with the 22 individual detectors if they had all been used with one acquisition system and computer. One system stored the data for the detectors at 0°, ± 12° and ± 24°. It was called the "fast" system since the timing signals for that system were obtained from discriminators connected directly to the fast signal outputs of the preamplifiers which were used. This is appropriate for the higher energy proton recoil pulses produced at these angles. The other system stored data for detectors at ± 12°, ± 24°, ± 36°, ± 48° and ± 60°. It was called the "slow" system since the timing signals for that system were obtained from discriminators connected to the amplified output of the preamplifiers. This system is appropriate for the lower energy proton recoil pulses produced at these angles. The storing of data for the ± 12° and ± 24° detectors in both computers allows the two data acquisition systems to be normalized with no concerns about uncertainties in the calculation of dead time losses. Also this redundancy allows consistency checks to be made.

Tantalum collimators placed in front of the ΔE detector defined the solid angles for each ΔE-E detector pair at each angle. These collimators were circular with an ID of 0.95 cm for all detector angles except 60°. Elliptical-type collimators with a vertical dimension of 0.79 cm and a horizontal dimension of 0.76 cm were used for the detectors at 60°. These special collimators reduced the angular spread so that kinematic broadening was reduced. This improvement allowed better separation between signal and background. Information about the solid angles for all the detectors was obtained by counting with a very uniform ^{239}Pu alpha-particle source, placed at the sample position, which has an area similar to that of the hydrogen scattering sample. In Fig. 2, the results of the alpha-particle measurements are shown. Data were taken with both the fast and slow systems. There is excellent agreement between these two systems for the common detectors at ± 12° and ± 24°.

The reduced counting rate for the 60° detectors, as is evident in the figure, occurs due to the smaller area of those collimators. The experiment does not require absolute measurements of the solid angles or differential cross sections since the shape of this angular distribution is the quantity in question. Thus the thin films used for hydrogen samples in this experiment need only be analyzed for impurities and not the absolute hydrogen content. As noted previously, the very accurately known hydrogen total scattering cross section can be used to normalize the relative differential cross section measurements.

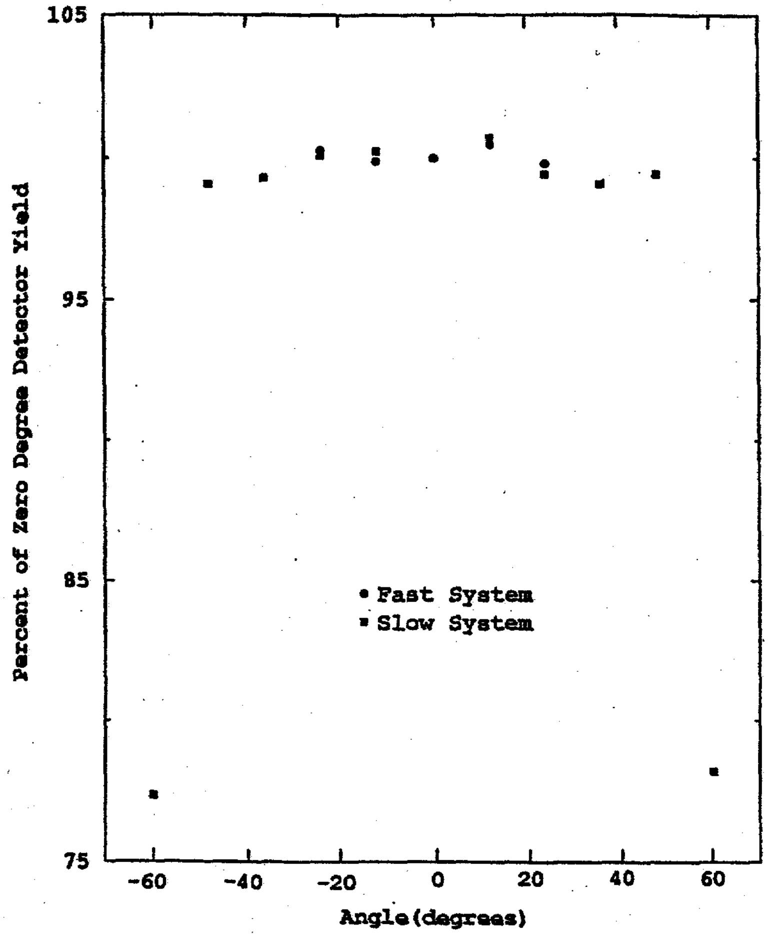

Figure 2. Measurements of the ^{239}Pu alpha-particle counting rates in the detector telescopes for determination of the relative solid angles.

Data Analysis and Results

Digitized pulse height information from the detectors was stored on the disk of a personal computer in a multi-parameter mode so that they could be analyzed under different conditions after the experiment was finished. Figure 3 shows data for the telescope at 0°. This figure shows pulse height from particle energy deposited in the E detector vs pulse height from particle energy deposited in the ΔE detector. Background has not been subtracted from these data. The vertical axis shows the number of events.

The large well-separated peak is the proton recoil peak of interest to this experiment. The remainder of the spectrum is background which is largely produced by (n,z) reactions on silicon. The larger background in this detector results from its being in the direct neutron beam whereas all the other detectors see only scattered neutrons. The negative Q-values of the background reactions provide good separation between the recoil protons and the background.

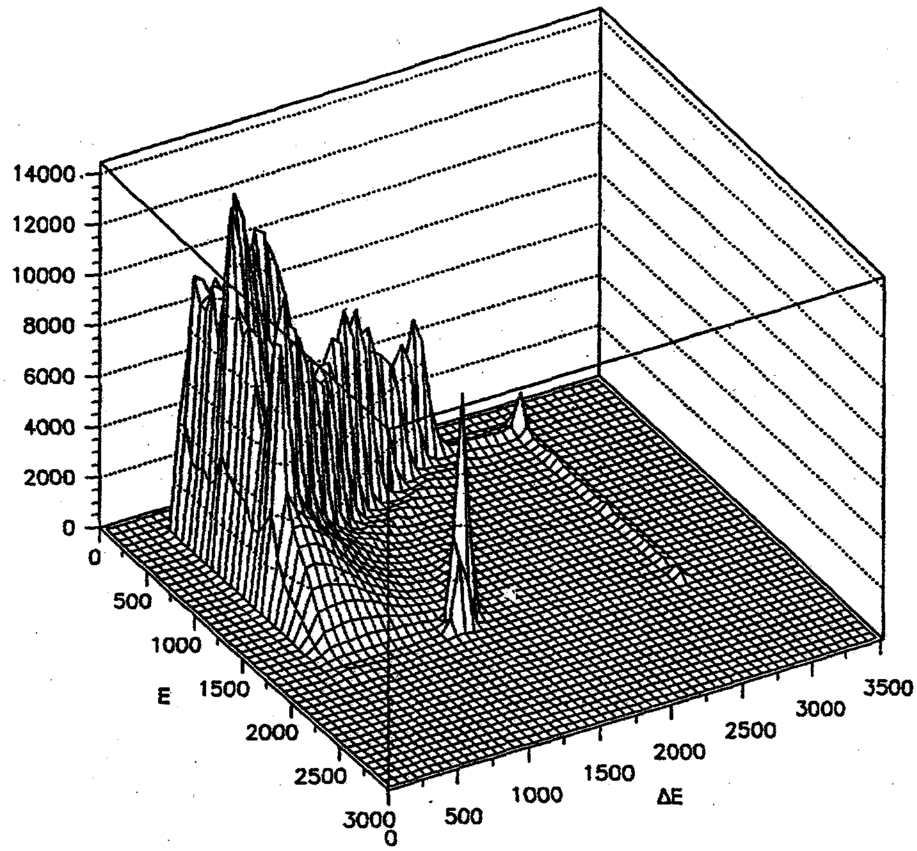

Figure 3. Two-dimensional display of pulse height spectra for ΔE and E detectors for a foreground run with the 0 ° telescope.

The data for each telescope were analyzed by using two-dimensional spectra similar to that shown in Fig. 3 with a gate drawn around the region containing the elastically scattered protons. The same gate was used for the foreground (sample-in) and background (sample-out) data. Pulse height spectra for both the foreground and background data were generated by summing the bins contained in the two-dimensional gates referred to above. From the sum of the background subtracted pulse height distribution data and the relative solid angles, the relative angular distribution was obtained.

A comparison of the results obtained on the left vs the right sides of the beam axis for the angular distribution measurement using the thick sample is shown in Fig. 4. This sample is too thick to provide a measurement at 60°. For illustrative purposes, measurements made with a detector to the left of the neutron beam (0°) have been reduced in angle by 2° and those made with a detector to the right of the neutron beam have been increased in angle by 2°. There is good agreement for the corresponding measurements made on both sides of 0°.

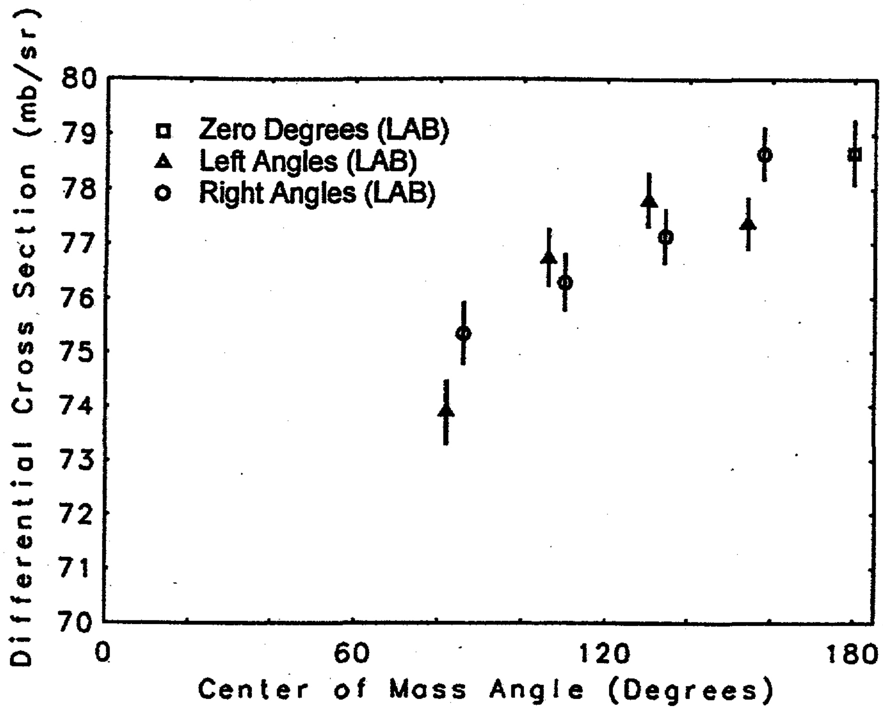

Figure 4. Comparison of the cross section results obtained on the left vs the right side of the beam axis. For illustrative purposes, data obtained with a detector located to the left of the beam axis have been reduced in angle by 2° and those obtained with a detector located to the right of the beam axis have been increased in angle by 2°.

In Fig. 5, the data from the telescopes on the left and right sides of the beam axis are combined to give preliminary results for the thick film sample. The uncertainties shown are one standard deviation statistical uncertainties. Also shown in Fig. 5 are the ENDF/B-V, ENDF/B-VI and Arndt FA-98 [7]evaluations. Comparisons can be made of the shape of the present measurements with these evaluations. The present preliminary results appear to be in best agreement with the Arndt evaluation and in worst agreement with the ENDF/B-VI evaluation. The addition of the point at 60°, which should be possible with the completion of the thin sample analysis, will allow more definite conclusions to be reached. Also with the inclusion of that point, a polynomial fit to the experimental data will be made so that this work can be normalized to the well-known total elastic scattering cross section.

Work is currently underway to model this experiment in detail using Monte Carlo techniques to ascertain loss mechanisms for the recoil protons. The simulation follows proton recoils as they move through the sample including scattering from the carbon and hydrogen atoms and then scattering from the silicon atoms in the ΔE detector. Relevant finite-size effects, geometrical parameters, and energy loss mechanisms are included in the calculations. The analysis will be done for both the thick and thin samples. Plans are being made for an extension of this experiment to ~14 MeV neutron energy after completion of the 10 MeV analyses. This will allow direct comparisons with the data sets which caused the large cross sections at back angles in the ENDF/B-VI evaluation.

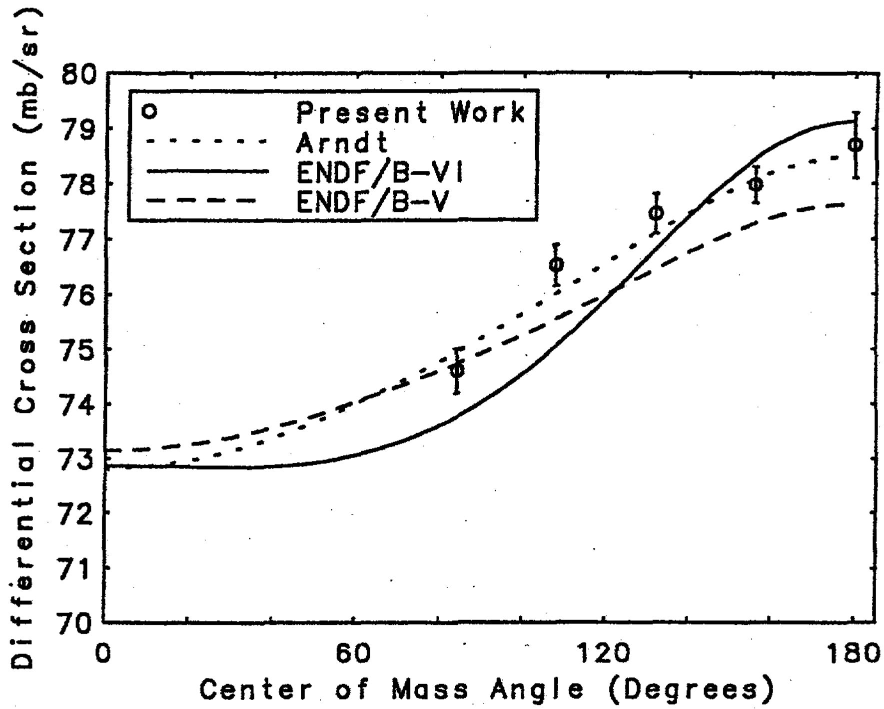

Figure 5. Preliminary measurement of the differential H(n,n) cross section at 10 MeV neutron energy compared with the ENDF/B-V, ENDF/B-VI and Arndt FA-98 evaluations.

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