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CERTAIN NEUTRON PROPERTIES OF MATERIALS

Part II

by

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ABSTRACT

Back scattering and poor-geometry transmission scattering measurements were described for neutrons of 1.5 and 3 Mev in a previous report (Part I). In the present report further experiments at 3 Mev are described, and also similar measurements for neutrons of 600-kev energy.

A. TRANSMISSION EXPERIMENTS—2.8-MEV NEUTRONS

In the transmission experiments with 2.8-Mev neutrons, described in Part I, the smallest limiting scattering angle was 60°. For calculating the transport cross section, it was desirable to know the cross section for the scattering of neutrons through smaller angles. For this purpose transmission experiments were carried out using a limiting angle of 30°.

The experimental arrangement was the same as that described in Part I, and shown in Figure 10A (Part I). It was found that at the large distance from the source used in the 30° measurements, the detector recorded an appreciable number of neutrons which did not come directly from the source. These neutrons are probably reflected by the floor. In order to determine the number of such neutrons, a long paraffin cylinder was placed between the source and the detector and recoils were counted with this cylinder in place. The observed neutron background remained quite constant over long periods of time. The background was subtracted both from the count observed in the presence of the scatterer and from that due to the direct beam.

In Table 1, which is a supplement to Table 1 (Part I), a number of additional scatterers are listed which were used in the present experiments. In Table 2 the cross sections found for 30° transmission scattering of 2.8-Mev neutrons and the average deviations of the individual runs from the mean are given. The "number of sample" refers to the scatterers listed in Tables 1 (Part I) and 1. In view of the small solid angle subtended by the scatterer at the detector, one would expect that the cross section should not depend appreciably on the bias used. The results are in agreement with this expectation.

In the literature a number of good-geometry scattering measurements may be found using neutrons of about the same energy as those used in the present work. The cross sections measured by other authors are consistently larger than those found in the present work. A possible explanation of this discrepancy is the well-known fact that the elastic scattering of fast neutrons has a strong forward maximum. In order to investigate this effect, some measurements were carried out using a lead disk small enough so that the limiting scattering angle was only 5°. With this arrangement, a good-geometry scattering cross section of about 6.9 barns was found. This value is higher than good-geometry cross sections found in the literature and indicates very strong small-angle scattering. This shows that a comparison of the present 30° measurements with good-geometry measurements is not possible.

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* This report is a sequel to MDDC-485 (H. H. Barschall, E. Graves, J. H. Manley, V. F. Weisskopf, Certain Neutron Properties of Materials—Part I, LADC-132), hereafter referred to as Part I.

Table 1. Samples used in scattering experiments.

Sample No.	Substance	Mol. or at. wt.	Thickness of sample (cm)	Area (cm^2)	kg	Density (g/cm^2)	Mol. or at/cm^2 x 10^{-24}	n x 10^{-24} per cm^3	Optimum	
									Density (g/cm^3)	n x 10^{-24} per cm^3
22	C	12.0	1.27	506	0.981	1.53	0.0972	.0766	1.60	0.0804
23	W	184	4.44	506	7.82	3.48	0.0505	.0114	16.8	0.0550
25	BeO	25	4.44	511	3.12	1.40	0.149	.0337	2.5	0.0602
27	BeO	25	1.23	506	1.43	2.31	0.0680	.0553	2.5	0.0602

B. BACK-SCATTERING EXPERIMENTS WITH GAS CHAMBER AND 3-MEV NEUTRONS

Back-scattering experiments with a directional detector and 3-Mev neutrons were described in Part I. It was pointed out there that the detector used in the experiments is sensitive mostly to elastically scattered neutrons. Since the transmission experiments showed the presence of many inelastically scattered neutrons, the necessity of repeating the back-scattering experiments using a detector which is sensitive also to neutrons of lower energy became apparent. Such back-scattering experiments are more advantageous for the measurement of inelastic scattering than the transmission experiments since the latter require the taking of second differences. Furthermore, a comparison of transmission and back-scattering experiments enables one to obtain an estimate of the number of inelastically scattered neutrons whose energy is less than the lowest bias energy used.

In these back-scattering experiments the same shadow cone as in Part I was used. The end of the cone was at a distance of 1.5 inches from D_2O-ice target. The center of the scattering disk was 16 inches from the target, and the distance from the center of the scatterer to the center of the detector was 2.75 inches. In order to make the back-scattering and transmission experiments strictly comparable, the axis of the cone was again placed at an angle of 60°, with respect to the D-beam. It was found, however, that with this arrangement an appreciable number of neutrons was still detected in the presence of the cone. This background was larger than the count due to the scatterer. The background might have been caused by neutrons which originated in parts of the accelerating tube other than the target. This assumption is corroborated by the fact that the background was reduced appreciably when observations were carried out in the forward direction (0° with respect to D-beam). In the latter case, the background was always smaller than the count due to the scatterer. Consequently, the back-scattering experiments were carried out in the forward direction in spite of the resulting difference in primary neutron energy for the transmission and back-scattering experiments.

In a preliminary experiment, the width of shadow produced by the cone was measured. The detector was moved in 1-inch steps on a straight line in a horizontal plane 16 inches from the target (corresponding to the position of the scatterer). It was found that, within the experimental error, the shadow for the neutrons agreed with the geometrical shadows.

Table 3 shows the results of the back-scattering experiments at 3.09 Mev. The energy loss in an elastic encounter with a carbon nucleus is sufficient to reduce the neutron energy almost to the highest bias energy used. Consequently, the number of scattered neutrons could not be measured at the highest bias energy when carbon was used as a scatterer. The same consideration holds for BeO. The cross sections were calculated using the integral evaluated by Olum (LA-45). The values listed for C and BeO are not corrected for the change of sensitivity of the detector because of energy loss in elastic encounters.

C. EXPERIMENTS USING 600-KEV NEUTRONS

1. Detector

The extension of scattering experiments to lower primary-neutron energies was made possible by the development of a suitable detector.

It was attempted at first to use the same ionization chamber which served as a detector, i.e., the 1.5-Mev experiments. The presence of X rays introduced difficulties, however. The electrons produced by X rays in the chamber caused a variable widening of the noise background and resulted in a shift of the effective bias. In addition, the sensitivity of the chamber as a function of neutron energy varied so rapidly that an interpretation of the data obtained was nearly impossible.

A more suitable detector was the proportional counter shown in Figure 1. The guard rings were maintained at the same voltage as the center wire and there was no trouble with spurious leakage pulses. The counter was filled to 76 cm pressure of deuterium, which was purified by passing the gas through palladium. There may have been as much as 1 per cent hydrogen. Deuterium was used rather than hydrogen because of its lower rate of change of cross section with neutron energy in this region. The electrical capacity of the counter wire and leads to the grid of the first tube of the amplifier was of the order of 10 μμf. This capacity together with the 0.5 megohm resistor in the voltage lead gave a pulse width of about 5 μsec and, therefore, a resolving time of 10 or 20 μsec for counting pulses from the counter. The gas amplification at the operating voltage was approximately 100 as determined by measuring pulse height corresponding to a given energy recoil particle as a function of voltage on the center wire. At voltages below 1800, the pulse height was nearly independent of voltage,

Table 2. Transmission 2.8 Mev (30° scattering, σ in barns).

Sample No.	Substance	0.7-Mev bias	1.4-Mev bias	2.1-Mev bias
1	C	1.46±2%	1.39±4%	1.49±6%
25	BeO	3.29±8%	3.20±4%	2.91±6%
7	Fe	2.53±4%	2.48±6%	2.72±3%
15	Pb	4.57±2%	4.48±5%	4.42±3%
10	W	4.48±4%	4.52±6%	4.45±6%

Table 3. 3.09-Mev back scattering (σ in barns).

Sample No.	Substance	0.77-Mev bias	1.55-Mev bias	2.32-Mev bias
1	C	$1.63 \pm 5\%_{+}$	$1.11 \pm 6\%_{+}$	
4	Al	$.89 \pm 2\%_{+}$	$.63 \pm 6\%_{+}$	$.33 \pm 7\%_{+}$
7	Fe	$1.19 \pm 3\%_{+}$	$.80 \pm 5\%_{+}$	$.50 \pm 17\%_{+}$
10	W	$1.18 \pm 7\%_{+}$	$.57 \pm 7\%_{+}$	$.37 \pm 8\%_{+}$
15	Pb	$2.32 \pm 9\%_{+}$	$1.87 \pm 9\%_{+}$	$1.57 \pm 10\%_{+}$
25	BeO	1.87±8%	1.04±8%	

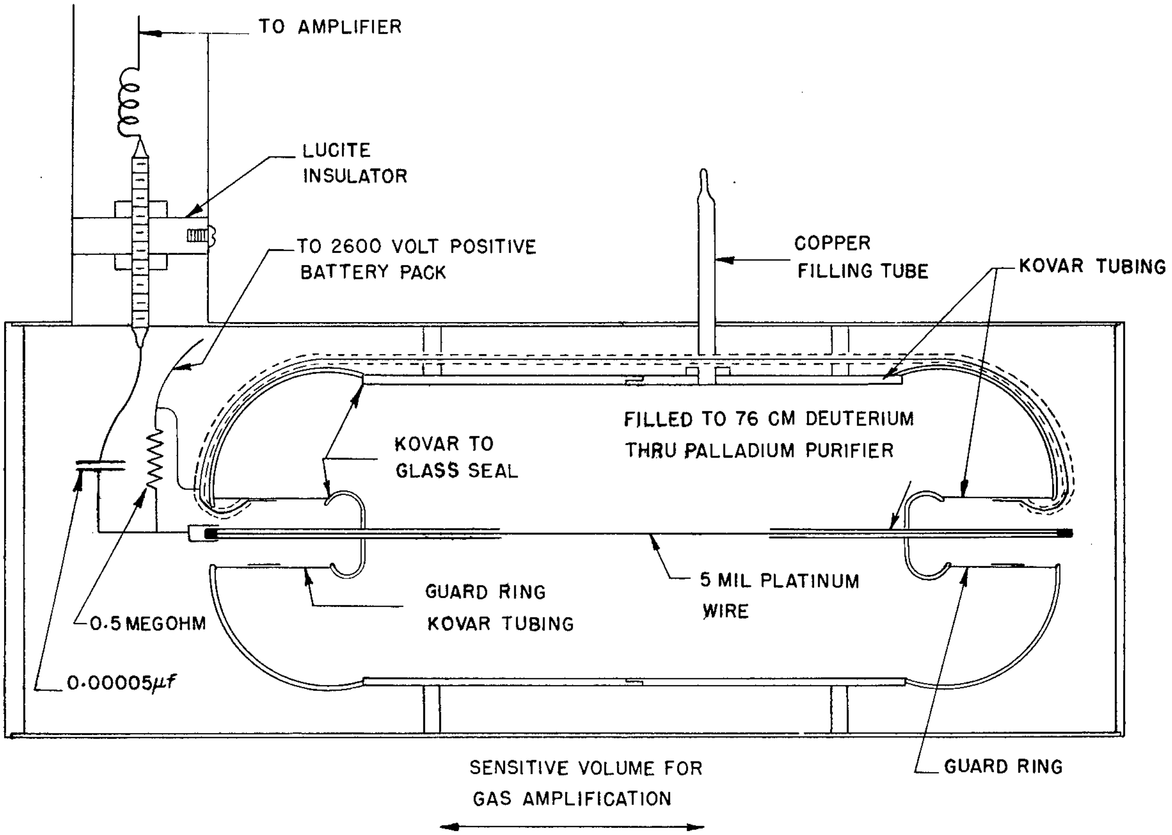

Figure 1. Cylindrical proportional counter.

indicating that below 1800 volts the counter behaved as an ionization chamber with no gas amplification. The stopping power of the gas filling was approximately such that maximum-energy deuteron recoils from 1-Mev neutrons barely lost all their energy in crossing the counter.

An undesirable feature of the counter is its different response to neutrons incident in different directions. The sensitivity to neutrons incident parallel to the central wire is approximately 24 per cent higher than that to neutrons incident at right angles to the wire. This effect is probably due to recoils entering the sensitive volume from the gas volume at the ends of the counter.

In all the experiments the counter was used with the central wire perpendicular to the direction of the direct beam. The anisotropic response will tend to yield too low cross sections in transmission experiments and too high cross sections in back-scattering experiments.

2. Transmission Experiments

The Li(p,n) reaction served as a neutron source in these experiments which were carried out in cooperation with group P-2.

For an evaluation of the scattering experiments it is essential to know the sensitivity of the detector as a function of neutron energy. The yield of the Li(p,n) reaction at various proton energies is not sufficiently well known to obtain the absolute number of neutrons from it. The ideal monitor would be one whose sensitivity does not vary with neutron energy. The "long counter" developed and tested by group P-2 appears to have approximately this property. This counter is similar to the one described by A. O. Hanson,[1] except for the fact that U^{235} is used instead of boron. The "long counter" was used as a monitor for obtaining a sensitivity curve and it was assumed that its response as a function of energy is flat in the energy interval used.

Figure 2 shows the response of the proportional counter as a function of neutron energy for the three different biases used in the scattering experiments. It appears that the detector has a fairly flat response over quite a large range of energies.

The experimental curves deviate considerably, however, from calculated curves (LAMS-39) even at low neutron energy where the wall effect is small. A large part of this deviation may be due to the change with neutron energy of the volume from which recoils are counted.

In Part I.A it was explained that by a proper choice of the scattering axis with respect to the proton beam it is possible to minimize the corrections for anisotropic neutron flux incident on the scatterer. Figure 3 shows the result of an experiment in which the counter was moved on a circle about the Li target. The response of the detector as a function of the angle with respect to the proton beam is shown for the three biases used in the scattering experiments, the neutron energy being 600 kev at 60°. An evaluation of the curves yields 60° as the best angle for the scattering axis, and for this angle no correction for the anisotropic neutron flux is necessary.

The geometry used in the transmission experiments is the same as that shown in Figure 10 (Part I) with $\alpha = 60°$. All transmission measurements are corrected for the background of neutrons which did not come directly from the target. The results are tabulated in Table 4. Since the scatterer reduces

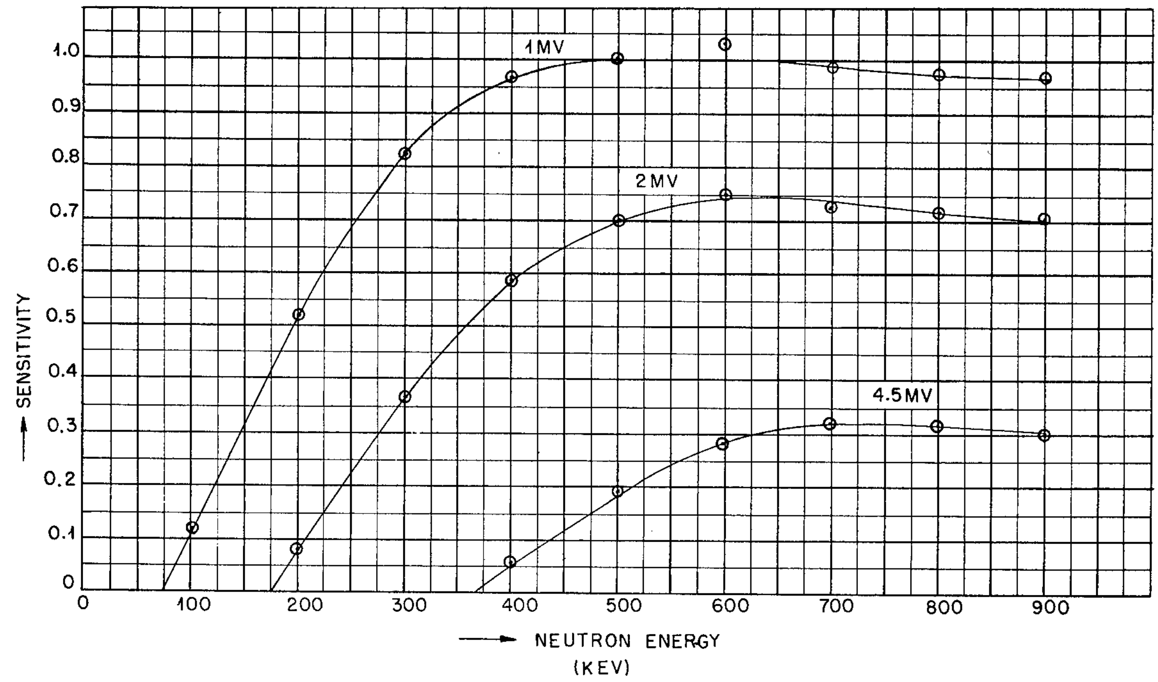

Figure 2.

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[1] A. O. Hanson, CF-618.

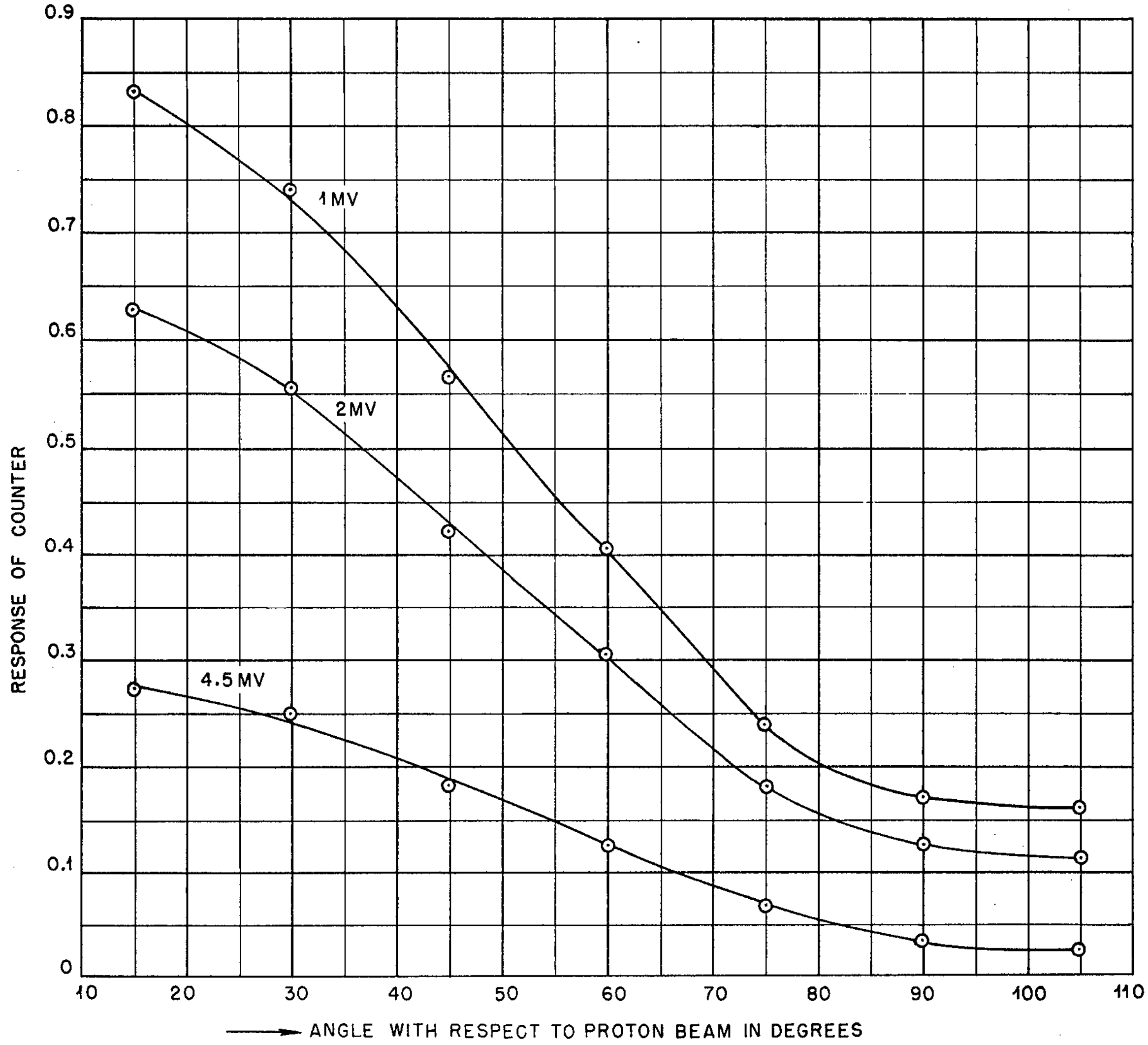

Figure 3. Response of proportional counter.

the neutron flux appreciably at this energy, the question of double scattering was investigated by using a carbon and tungsten scatterer of appreciably smaller thickness. The cross section for the two thicknesses agree within the experimental error so that one may conclude that for the thicker scatterer the effect of double scattering is negligible.

3. Back-Scattering Experiments

The arrangement used in the back-scattering experiments is the same as that shown in Figure 7 (Part I) except for the angle with the proton beam which was 60° for the 600-kev neutrons.

The results of the back-scattering experiments are tabulated in Table 5. The cross sections are computed again as described in LA-45.

Table 4. Transmission (in barns).

Sample No.	Substance	30°			60°			90°		
		1-Mev bias (80 kev)	2-Mev bias (175 kev)	4.5-Mev bias (360 kev)	1-Mev bias (80 kev)	2-Mev bias (175 kev)	4.5-Mev bias (360 kev)	1-Mev bias (80 kev)	2-Mev bias (175 kev)	4.5-Mev bias (360 kev)
27	BeO	5.72 ±9%	5.68 ±8%	6.05 ±6%	3.33 ±3%	3.44 ±2%	3.81 ±5%	1.37 ±6%	1.51 ±6%	2.34 ±9%
23	W				3.36 ±5%	3.15 ±12%	3.65 ±12%			
10	W	5.01 ±3%	4.97 ±3%	4.95 ±4%	3.07 ±1%	3.12 ±2%	3.32 ±3%	1.43 ±4%	1.54 ±3%	2.04 ±2%
15	Pb	4.84 ±4%	4.86 ±2%	4.83 ±5%	3.32 ±2%	3.23 ±2%	3.05 ±5%	1.94 ±5%	1.91 ±5%	2.03 ±6%
7	Fe	2.02 ±3%	1.97 ±6%	1.97 ±6%	1.17 ±10%	1.12 ±4%	1.14 ±3%	0.44 ±5%	0.45 ±3%	0.49 ±5%
22	C	3.03 ±1%	2.93 ±1%	3.01 ±11%	1.91 ±7%	1.91 ±13%	2.03 ±8%			
1	C	2.81 ±1%	2.83 ±1%	2.92 ±2%	1.76 ±2%	1.81 ±2%	2.08 ±3%	0.84 ±1%	0.95 ±2%	1.40 ±4%

Table 5. Back scattering 600 Kev (σ in barns).

Sample No.	Substance	1-Mev bias (80 kev)	2-Mev bias (175 kev)	4.5-Mev bias (360 kev)
27	BeO	4.36±4%	3.90±3%	1.93±3%
10	W	4.16±2%	3.94±2%	3.10±4%
15	Pb	4.51±3%	4.43±2%	4.43±3%
7	Fe	1.67±3%	1.61±2%	1.41±2%
1	C	2.04±1%	1.85±4%	0.89±4%

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