NEUTRON CROSS SECTIONS OF POLYETHYLENE AND LIGHT WATER IN THE ENERGY RANGE 8.2 x 10^{4} TO 0.13 eV

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Abstract

The total neutron cross-sections σ_T of polyethylene and light water have been measured, as a function of neutron wavelength, in the neutron energy interval 0.13 to 8.2×10^{-4} eV using a chopper-time-of-flight spectrometer and a crystal spectrometer, at the IEA research reactor. The measurement, made with good precision and a great number of points, represent an improvement to the knowledge of σ_T for these materials. The polyethylene experimental results are compared with calculations based on different data and hypothesis about the molecular dynamics of this polymer. The calculated values of Kirouac et al(Trans. Amer. Nucl. Soc. 12, 672, 1969) agree satisfactorily with our results, also in the sub-thermal region ($E < 10^{-2}$ eV), where there was a discrepancy between experimental and calculated values. Results obtained for water are in good agreement with previous measurements, both in the thermal and sub-thermal region. They also agree with calculated values based on the models proposed by Koppel-Young and Mc Murrey-Russel, in the thermal region. The slopes of the scattering cross section per hydrogen atom curves, as a function of neutron wavelength, in the range 4.8 to 10Å, have been derived.

1. Introduction

The total neutron cross section represents a good integral check of the computed scattering kernels for water and polyethylene. Therefore it is important to measure this cross section with good statistical accuracy.

The experimental measurements found in the literature have good precision in the thermal region but, for lower energies, there are only a few measurements with large uncertainties.

In the present experiment the total neutron cross section for water and polyethylene has been measured in the energy interval 0.0008 - .13 eV with a precision that represents an improvement in the knowledge of these cross sections.

The total cross section of polyethylene has been measured by Back et al[1], for neutrons in the energy interval 0.002 - 1.0 eV and by Armstrong[2] in the energy interval 0.004 - 1.0eV. The present experiment includes results in the energy range 0.0008 - 0.002 eV, where no data have been published previously[3] [4]. The only exception is the result obtained by Von F. Lasinger and Rauch[5] using the whole neutron spectrum transmitted by a bismuth filter (average energy $\cong$ 0.001 eV). Moreover, in the energy interval 0.002 - 0.008 eV, the results here presented have a much better statistical accuracy than the previous measurements.

The total neutron cross section of H_2O in the thermal and sub-thermal region has been measured in several laboratories (6-10). The data published until 1964 can be found in the 2nd. edition of BNL-325. The number of measured values obtained in the present experiment is the same obtained in all the previous measurement in the interval 0.0008 - 0.004 eV, with comparable statistical fluctuation.

The experimental results are compared with the scattering kernel models from Sprevak-Koppel[11] and Kirouac et al[12] for polyethylene, and from Nelkin[13], Koppel-Young[14] and McMurry et al[15] for water.

2. Models

Crystalline polyethylene is known to be formed of very long molecules having a plannar zig-zag shape with a CH_2 radical at each vertex.

The theoretical models for the calculation of the neutron scattering use the frequency spectrum constructed assuming that the polyethylene molocule is infinite and neglecting the interaction between the chains, since the coupling between neighboring chains is rather weak.

The present paper does not consider the first treatments of Goldman-Federighi[16], because the frequencies of the oscillators in this model are in contradiction with the experimental data obtained by optical methods, and Koppel-Young[17], which was improved by the Sprevak-Koppel model[11].

In the Sprevak-Koppel model, the dispersion relations for the infinite chain of CH_2 radicals and the polarization vector for each normal frequency are calculated using the set of force constants determined by Lin and Koening[18]. The weighted frequency spectrum is calculated using the computed dispersion relations and amplitude vectors.

The Kirouac et al model[12] takes rigorously into account the polarization vectors for the normal of vibration of the chain and performs a better orientation average over molecular position. It considers the linear polyethylene chain nearly degenerate, having only two polarization vectors, a longitudinal one and a transverse one. The calculation has been carried out with the frequency distribution of Linch et al[19].

The first model for water was formulated by Nelkin[13]. In this model the scattering units are freely recoiling H_2O molecules, which have torsional harmonic oscillations and isotropic internal vibrations in the O-H bonds directions and in the angle between them. This model was improved by Koppel and Young[14] who considered the spatial anisotropy of the proton vibration in the H_2O molecule. In this model the following system of forces acts on a proton: a force along the direction of the O-H bond, proportional to the change in the lenght of the bond and a force perpendicular to the bond and coplanar with the H_2O molecule, proportional to the change in the angle between two O-H bonds; the rotations of the whole molecule about its three principal axes of inertia are completely hindered by a harmonic torsional potential.

In another approach, McMurry et al[15] consider water as a mixture of 10% free H_2O molecules of mass 18, 45% aggregates of mass 75, and 45% aggregates of mass 150. They also assume that the internal vibrational modes of each molecule are unaffected by the clustering.

3. Experimental

The IEAR1 swimming pool reactor[20] [21], operating at 2 Mw, has been used as neutron source. Total cross-sections as a function of neutron wavelenght have been measured

using a curved slit slow-neutron chopper and time-of-flight spectrometer described elsewhere[22] [23]. The chopper was placed in front of a through tube (tangencial beam hole nº 13) so that the reactor core was not "seen" directly, the neutron source being a volume of moderator (H_2O) contained in the portion of the through tube located in front of the core. The distance from the center of the neutron source to the center of the chopper was 3.30m. A shielded proportional counter 12" long x 1" diameter, filled with ^3He gas at a pressure of 2 atmospheres, located at a known distance from the chopper, was utilized as neutron detector. Cadmium slits were used to define the neutron beam between chopper and detector. A smmall low efficiency BF_3 detector (99% transmission for 2200 m/s neutrons) 1" long x 1/4" diameter was located between the reactor beam hole and the chopper, for monitoring the neutron flux.

Experiments have been carried out at room temperature (295°K-297°K) with chopper speeds from 4000 to 7000 RPM, flight paths of 1.48 m and 2.66 m and 32 μsec channel length in a TMC 1024-channel time-of-flight analyser. The wavelength resolution varied from 0.1Å at λ = 1Å to 0.3Å, at λ = 10Å.

The total cross sections of polyethylene has also been measured using a crystal spectrometer[24] in the wavelength range 4-7Å. A magnetite (111) crystal was used as neutron monochromator and 10 cm Be polycrystalline as filter to eliminate order contamination in Bragg scattering. The results obtained with the crystal spectrometer agree with those obtained with the slow-chopper within the statistical errors.

Transmission measurements were made in the usual way, with the sample in and out the pulsed beam; background measurements were made with a 0.7 mm thick cadmium plate located between the sample position and the detector. Demineralized water has been utilized as H_2O samples. Sample purity was checked by its resistivity, equal to 1.6×10^6 ohm.cm. The polyethylene sample was a plate with uniform thickness (0.241 ± 0.03) cm, density (0.92 ± 0.01) g/cm^3, and crystallinity ≈ 50%, estimated from the sample density[25] [26]. As verified by Armstrong[2], the degree of crystallinity does not influence the total cross section values, since polyethylene is a scatterer essentially incoherent. Water samples were contained in cells made of alumimum 2S, with the following dimensions: diameter 70 mm, internal spacing 2.5 mm, window thicknesses 2.5 mm. The number of molecules of water per square centimeter, n, has been determined from the internal dimensions of the cells and the density of the liquid at room temperature. Uncertainties in the n value amount to about 3% for the water samples, and 0.6% for the polyethylene sample.

In-scattering and multiple scattering correction for each channel are very difficult to evaluate because of the contribution of inelastic scattering. A neutron inelastically scattered by the sample that reaches the detector has a different time-of-flight as compared with the transmitted neutrons. So, the contributions to the counting rate due to inscattering or multiple scattering by inelastic processes are distributed over many channels (wavelengths). In-scattering is minimized by the "good geometry" of the experimental arrangement, and multiple scattering by the utilization of thin samples. In the present experiment the overall corrections due to these two effects are estimated to be less than 1%.

Time-of-flight data processing and cross-section computation have been carried out by means of the code TVSC[22], using a IBM 1620 Mark II computer. The following calculations are carried out for each analyser channel: correction for counting losses; normalization of the counting data with respect to monitor reading; subtraction of the measured background; total

neutron cross-section computation from transmission measurements, with statistical errors; calculation of the wavelength for each channel number, according to the overall calibration.

The total cross-section per CH_2 unit in polyethylene, and per H_2O unit in water, can be written:

$$\sigma_T = \sigma_x + 2\sigma_a + 2(\sigma_s/H) \quad (1)$$

where: σ_x is the total cross-section of carbon (4.8 barns), or of oxygen (3.8 barns), for polyethylene and water, respectively:

σ_a is the absorption cross-section for hydrogen, assumed $1/v(\sigma = 0.332$ barns, for 2200 m/sec neutrons);

σ_s/H is the scattering cross-section per hydroden atom.

The numerical values for the cross-sections for carbon, oxygen and hydrogen were taken from BNL-325. Scattering cross-sections per hydrogen atom have been calculated by means of equation (1), using the measured total cross-sections σ_T, and the mentioned values for σ_x and σ_a.

4. Results

Polyethylene:

The measured values of σ_T for polyethylene are presented in table I and figure 1. The curves presented in this figure corresponds to calculated cross-sections published by Sprevach and Koppel[11] and by Kirouac et al[12]. The agreement between experimental results and theoretical curves are reasonable. The Kirouac at al curve shows a better fit in the low energy end of the data. This low energy portion of the total cross-section curve seems to be very sensitive to the frequency spectrum assumed in the calculations.

Light Water

The measured values of σ_T for light water are presented in table II and figure 2. Some results published by Russel, Neill, and Brown[9] are presented in the range 0.1 - 0.003 eV, for comparison. In the interval 5 to 10Å (0.003 to 0.0008 eV) all the experimental results previously published and compiled in BNL-325, 2nd ed.[6], and the data of Rush, Leung and Taylor[10], are shown. These previous results amount to about 23 measured values, as compared to 59 values obtained in the present experiment in the same interval (5 to 10Å), with a comparable statistical fluctuation at least in the interval 5 - 8Å.

Table III presents a comparison of experimental data with some values that have been calculated by means of the free gas, Nelkin[13], Koppel Young[14], and McMurry-Russel[15] models for light water. The calculated values have been taken from reference15.

Scattering Cross-Sections per H Atom:

The scattering cross-sections per hydrogen atom may be approximated by straight lines

$\sigma_s/H = a_s + b_s\lambda$, for $\lambda > 5$Å.

Tables I and II, and figure 3, present σ_s/H for polyethylene and H_2O as a function of neutron wavelength and energy. The cross-section slopes in the subthermal region are also shown. Slopes b_s were obtained by means of a weighted least-squares fit to the data. Table IV presents the cross-section slopes obtained in the present experiment as well as those obtained with previously published data.

Figure Captions

Fig. 1 - Measured values of σ_T for polyethylene are presented as a function of neutron energy. Calculated cross-sections by Sprevak and Koppel[11] and by Kirouac et al[12] are shown for comparison.

Fig. 2 - Measured values of σ_T for light water are presented as a function of neutron energy. Published results by Russel et al[19] in the range 0.1 to 0.003 eV and by Rush et al[10] and BNL-325[6] in the range 0.003 to 0.0008 eV are shown for comparison.

Fig. 3 - σ_s/H for polyethylene and H_2O as a function of neutron wavelength and energy. The least-squares fits in the subthermal region and the obtained slopes are also shown.

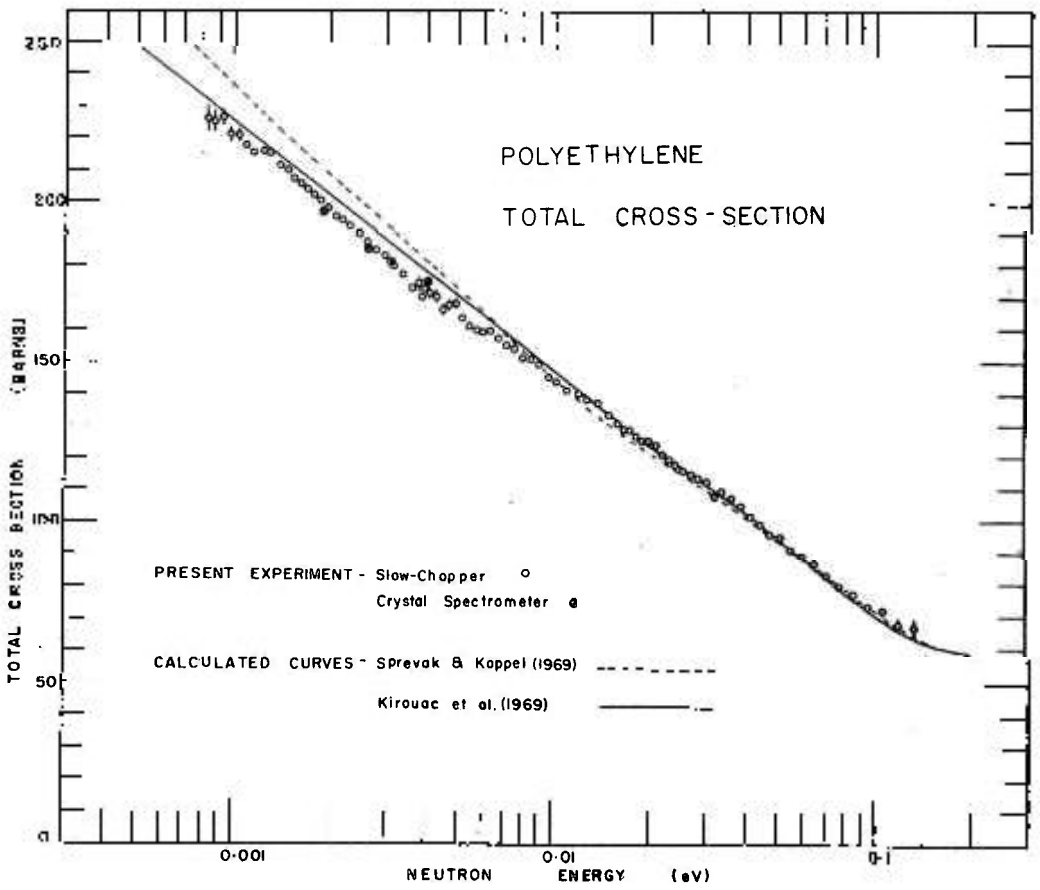
POLYETHYLENE
TOTAL CROSS-SECTION
PRESENT EXPERIMENT - Slow-Chopper o
Crystal Spectrometer e
CALCULATED CURVES - SPrevak & Kappel (1969)
Kirouac et al. (1969)
TOTAL CROSS SECTION (BARNS)
250
200
150
100
50
0
0·001
0·01
0·1
NEUTRON ENERGY (eV)

FIG. 1

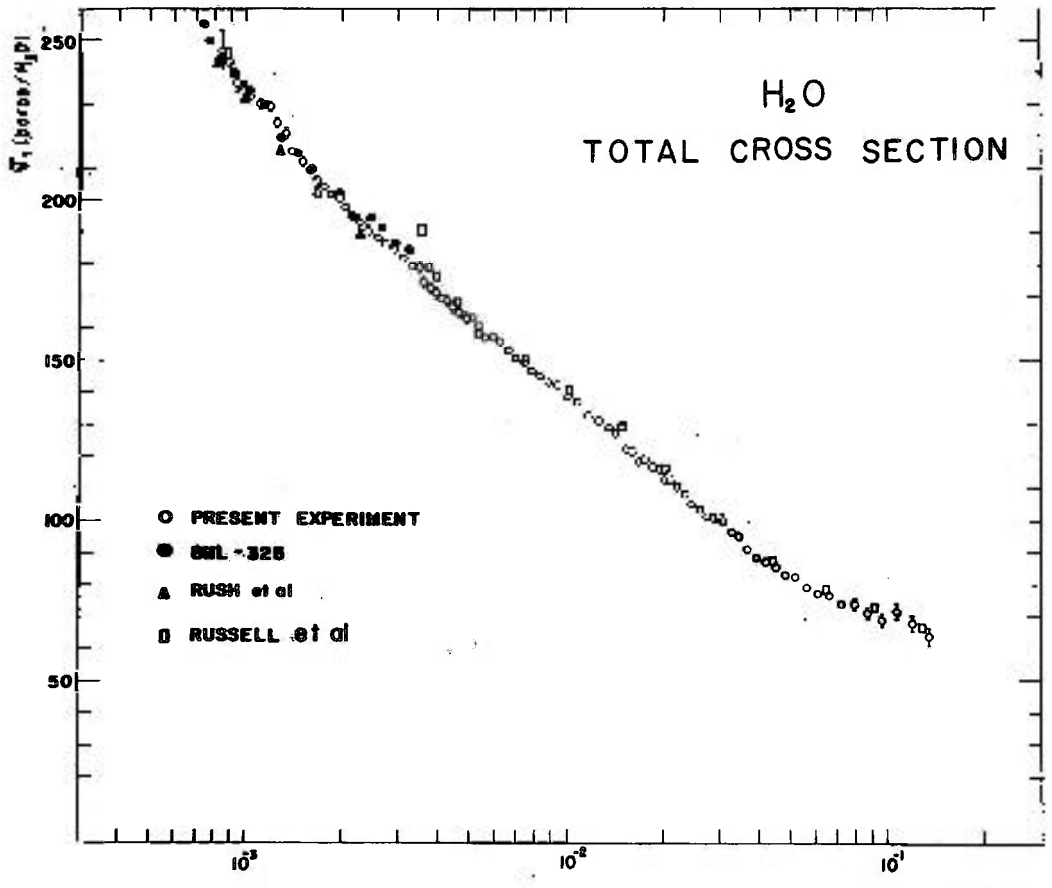
H_2O
TOTAL CROSS SECTION
σ_t (barns/H_2O)
250
200
150
100
50
O PRESENT EXPERIMENT
● BNL-325
▲ RUSH et al
□ RUSSELL et al
10^{-3}
10^{-2}
10^{-1}
E(ev)

FIG. 2

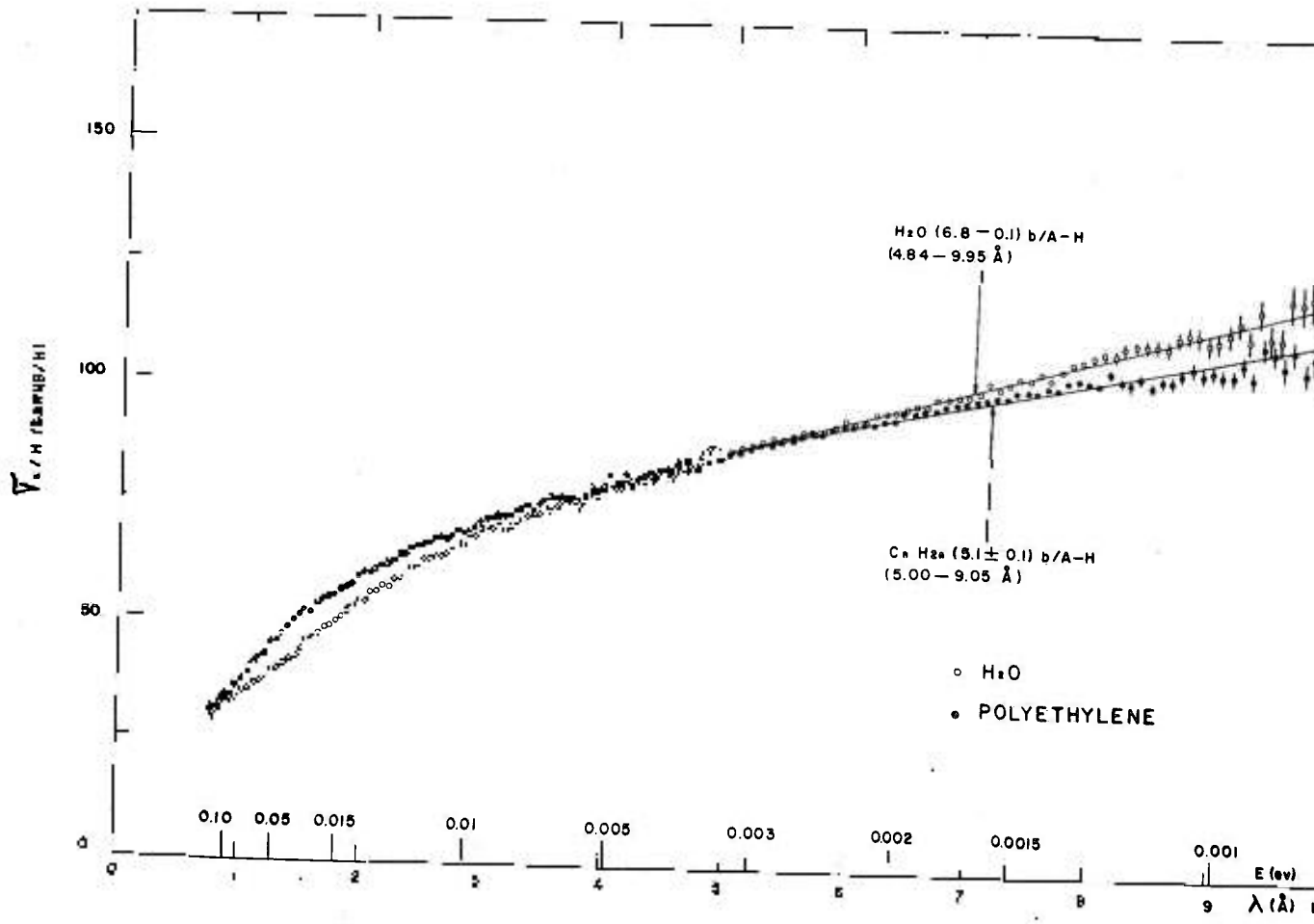
150
100
50
0
H₂O (6.8 − 0.1) b/A−H
(4.84 − 9.95 Å)
Cₙ H₂ₙ (5.1 ± 0.1) b/A−H
(5.00 − 9.05 Å)
○ H₂O
● POLYETHYLENE
0.10
0.05
0.015
0.01
0.005
0.003
0.002
0.0015
0.001
E (ev)
λ (Å)

FIG. 3

TABLE I
NEUTRON CROSS SECTIONS OF POLYETHYLENE

TIME OF FLIGHT DATA

λ (Å)	E_o(eV)	σ_T(barns/CH_2)	$\epsilon(\sigma_T)$	σ_s/H(barns/H)	$\epsilon(\sigma_s$/H)
0.77	1.36×10^{-1}	66.6	2.3	30.7	1.1
0.82	1.21	67.5	1.4	31.2	0.7
0.87	1.08×10^{-1}	72.1	1.2	33.5	0.6
0.92	9.73×10^{-2}	73.1	1.1	34.0	0.3
0.96	8.79	77.0	1.0	35.9	0.5
1.01	7.99	79.4	0.9	37.1	0.5
1.06	7.28	82.5	0.9	38.6	0.5
1.11	6.67	86.3	0.9	40.6	0.5
1.15	6.13	89.1	1.0	41.9	0.5
1.20	5.66	90.3	1.0	42.5	0.5
1.25	5.24	95.4	1.0	45.1	0.5
1.30	4.86	95.8	1.0	45.2	0.5
1.34	4.52	99.0	0.9	46.8	0.4
1.39	4.22	101.4	0.8	48.1	0.4
1.44	3.94	104.3	0.8	49.5	0.4
1.49	3.69	107.1	0.8	50.8	0.4
1.53	3.47	109.1	0.8	51.8	0.4
1.58	3.26	107.6	0.8	51.1	0.4
1.63	3.08	112.1	0.8	53.4	0.4
1.68	2.90	113.7	0.8	54.1	0.4
1.72	2.74	114.7	0.8	54.6	0.4
1.77	2.60	115.4	0.9	55.0	0.4
1.82	2.47	117.6	0.9	56.1	0.4
1.87	2.34	119.3	0.8	56.9	0.4
1.91	2.23	120.5	0.8	57.5	0.4
1.96	2.12	123.8	0.8	59.2	0.4
2.01	2.02	125.3	0.8	59.9	0.4
2.06	1.93	125.6	0.8	60.0	0.4
2.10	1.84	126.9	0.9	60.6	0.5
2.15	1.76	128.5	1.0	61.5	0.5
2.20	1.69	128.8	1.0	61.6	0.5

TABLE I - cont.

λ(Å)	E_o(eV)	σ_T(barns/CH_2)	$\epsilon(\sigma_T)$	σ_s/H(barns/H)	$\epsilon(\sigma_s/H)$
2.25	1.62	130.6	1.0	62.5	0.5
2.30	1.55	133.6	0.9	64.0	0.5
2.34	1.49	133.8	0.9	64.0	0.4
2.39	1.43	136.4	0.9	65.4	0.4
2.44	1.37	137.6	0.9	65.9	0.4
2.49	1.32×10^{-2}	137.9	0.9	66.1	0.4
2.53	1.27	138.1	1.0	66.2	0.5
2.58	1.23	140.5	1.0	67.4	0.5
2.63	1.18	141.2	1.1	67.7	0.5
2.68	1.14	140.1	1.2	67.2	0.6
2.72	1.10	141.9	1.2	68.0	0.6
2.77	1.06	144.5	1.2	69.3	0.6
2.82	1.03×10^{-2}	143.2	1.1	68.7	0.5
2.87	9.95×10^{-3}	144.6	1.1	69.4	0.5
2.91	9.63	145.8	1.1	69.9	0.5
2.96	9.32	148.2	1.1	71.2	0.6
3.01	9.03	149.6	1.1	71.9	0.6
3.06	8.75	150.0	1.1	72.0	0.6
3.10	8.48	151.3	1.1	72.7	0.6
3.15	8.23	150.9	1.2	72.5	0.6
3.20	7.99	151.0	1.2	72.5	0.6
3.25	7.75	153.9	1.3	73.9	0.6
3.29	7.53	153.8	1.3	73.9	0.7
3.34	7.32	155.8	1.4	74.9	0.7
3.39	7.12	153.4	1.4	73.7	0.7
3.44	6.92	156.2	1.4	75.1	0.7
3.48	6.73	158.0	1.5	76.0	0.7
3.53	6.55	159.6	1.5	76.7	0.8
3.58	6.38	159.0	1.6	76.4	0.8
3.63	6.21	160.0	1.6	76.9	0.8
3.67	6.05	158.8	1.6	76.3	0.8
3.72	5.90	159.7	1.6	76.8	0.8
3.77	5.75	-	-	-	-
3.82	5.61	160.0	1.7	76.9	0.9

TABLE I - cont.

λ (Å)	E_o(eV)	σ_T(barns/CH_2)	$\epsilon(\sigma_T)$	σ_s/H(barns/H)	$\epsilon(\sigma_s/H)$
3.86	5.47	162.7	1.9	78.2	0.9
3.91	5.34	162.9	2.1	78.3	1.0
3.96	5.21	163.5	2.2	78.6	1.1
4.01	5.09	169.7	2.2	81.7	1.1
4.05	4.97	165.9	2.1	79.8	1.1
4.10	4.85	165.3	2.1	79.5	1.0
4.15	4.75	169.8	2.2	81.7	1.1
4.20	4.64	164.2	2.3	78.9	1.2
4.25	4.53	167.7	2.5	80.6	1.3
4.29	4.43	169.6	2.7	81.6	1.3
4.34	4.34	170.2	2.6	81.9	1.3
4.39	4.24	169.6	2.6	81.6	1.3
4.44	4.15	172.4	2.6	83.0	1.3
4.48	4.07	172.8	2.7	83.2	1.3
4.53	3.98	172.1	2.8	82.8	1.4
4.58	3.90	174.8	3.0	84.2	1.5
4.63	3.82×10^{-3}	173.8	3.4	84.8	2.0
4.49	4.05×10^{-3}	168.1	0.6	80.8	0.3
4.58	3.90	171.9	0.6	82.7	0.3
4.66	3.76	171.6	0.6	82.5	0.3
4.75	3.63	173.0	0.6	83.2	0.3
4.83	3.50	176.5	0.6	85.0	0.3
4.92	3.38	177.4	0.6	85.4	0.3
5.00	3.27	179.3	0.6	86.3	0.3
5.08	3.16	180.3	0.6	86.8	0.3
5.17	3.06	182.2	0.5	87.7	0.2
5.25	2.96	183.8	0.5	88.5	0.2
5.34	2.87	183.8	0.5	88.5	0.2
5.42	2.78	185.6	0.5	89.4	0.2
5.51	2.69	186.1	0.4	89.6	0.2
5.59	2.61	188.3	0.5	90.7	0.2
5.67	2.54	190.0	0.5	91.6	0.2
5.76	2.46	189.5	0.5	91.3	0.2

TABLE I - cont.

λ (Å)	E_o(eV)	σ_T(barns/CH_2)	$\epsilon(\sigma_T)$	σ_s/H(barns/H)	$\epsilon(\sigma_s$/H)
5.84	2.39	191.4	0.5	92.2	0.3
5.93	2.32	192.5	0.5	92.8	0.3
6.01	2.26	193.0	0.6	93.0	0.3
6.10	2.20	194.0	0.6	93.5	0.3
6.18	2.14	193.4	0.6	93.2	0.3
6.27	2.08	195.3	0.6	94.1	0.3
6.35	2.03	195.6	0.7	94.2	0.3
6.43	1.97	199.3	0.7	96.1	0.3
6.52	1.92	199.2	0.7	96.0	0.4
6.60	1.87	200.0	0.8	96.4	0.4
6.69	1.83	200.5	0.8	96.6	0.4
6.77	1.78×10^{-3}	202.3	0.8	97.5	0.4
6.86	1.74	202.7	0.9	97.7	0.4
6.94	1.70	204.1	0.9	98.3	0.4
7.03	1.66	204.6	0.9	98.6	0.5
7.11	1.62	205.5	1.0	99.0	0.5
7.19	1.58	206.9	1.0	99.7	0.5
7.28	1.54	206.4	1.1	99.4	0.5
7.36	1.51	209.1	1.1	100.8	0.6
7.45	1.47	209.8	1.2	101.1	0.6
7.53	1.44	209.5	1.2	100.9	0.6
7.62	1.41	211.5	1.3	102.0	0.6
7.70	1.38	211.1	1.4	101.7	0.7
7.78	1.35	214.2	1.4	103.2	0.7
7.87	1.32	215.1	1.5	103.7	0.8
7.95	1.29	214.4	1.6	103.3	0.8
8.04	1.26	213.5	1.7	102.9	0.8
8.12	1.24	218.1	1.8	105.2	0.9
8.21	1.21	215.3	1.9	103.7	0.9
8.29	1.19	213.9	1.9	103.1	1.0
8.37	1.16	216.8	2.0	104.4	1.0
8.46	1.14	213.6	2.1	102.8	1.0
8.54	1.12	216.0	2.3	104.0	1.1
8.63	1.10	215.9	2.3	103.9	1.2

TABLE I - cont.

λ (Å)	E_o(eV)	σ_T(barns/CH_2)	$\epsilon(\sigma_T)$	σ_s/H(barns/H)	$\epsilon(\sigma_s/H)$
8.71	1.08	219.1	2.6	105.5	1.3
8.80	1.06	221.4	2.7	106.7	1.4
8.88	1.04	219.0	2.9	105.5	1.4
8.97	1.02×10^{-3}	220.3	3.0	106.1	1.5
9.05	9.98×10^{-4}	218.7	3.1	105.3	1.5
9.14	9.80	218.5	3.3	105.2	1.6
9.22	9.62	223.9	3.6	107.8	1.8
9.30	9.44	218.0	3.6	104.9	1.8
9.39	9.28	231.2	4.4	111.5	2.2
9.47	9.11	228.6	4.4	110.1	2.2
9.56	8.95	223.1	4.6	107.4	2.3
9.64	8.79	229.6	5.1	110.7	2.5
9.73	8.64	221.0	5.1	106.3	2.5
9.81	8.50	227.3	6.3	109.4	3.1
9.89	8.35	221.4	6.6	106.5	3.3
9.98	8.21×10^{-4}	228.8	7.1	110.1	3.6
CRYSTAL SPECTROMETER DATA					
4.48	4.09×10^{-3}	174.6	0.4	84.1	0.2
5.11	3.14	181.9	0.8	87.6	0.4
5.53	2.68	185.1	0.9	89.1	0.5
6.51	1.93	196.0	1.1	94.4	0.6

TABLE II

NEUTRON CROSS SECTIONS OF LIGHT WATER

λ (Å)	E(eV)	σ_T(barns/mol.)	$\epsilon(\sigma_T)$	σ_s/H(barns/H)	$\epsilon(\sigma_s/H)$
0.78	1.34×10^{-1}	63.9	3.1	29.9	1.5
0.83	1.19	68.0	2.4	32.0	1.2
0.87	1.07	71.4	1.9	33.7	0.9
0.92	9.60×10^{-2}	68.8	1.6	32.9	0.8
0.97	8.68	70.5	1.4	33.2	0.7
1.02	7.89	73.9	1.3	34.9	0.6
1.06	7.20	74.1	1.2	35.0	0.6
1.11	6.60	76.9	1.1	36.4	0.6
1.16	6.07	77.4	1.1	36.6	0.5
1.21	5.60	79.4	1.1	37.6	0.5
1.25	5.18	82.3	1.0	39.1	0.5
1.30	4.81	83.3	0.9	39.5	0.5
1.35	4.48	85.4	0.9	40.6	0.4
1.40	4.18	87.3	0.9	41.5	0.4
1.45	3.91	88.5	0.9	42.1	0.5
1.49	3.66	91.5	1.0	43.6	0.5
1.54	3.44	95.7	1.0	45.7	0.5
1.59	3.24	96.2	0.9	46.0	0.5
1.64	3.05	98.8	0.9	47.2	0.4
1.69	2.88	101.1	0.8	48.4	0.4
1.73	2.73	101.5	0.8	48.6	0.4
1.78	2.58	103.5	0.8	49.6	0.4
1.83	2.45	105.3	0.9	50.5	0.4
1.87	2.33	108.3	0.9	51.9	0.4
1.92	2.21	110.4	0.8	53.0	0.4
1.97	2.11	112.9	0.8	54.2	0.4
2.02	2.01	112.5	0.8	54.0	0.4
2.06	1.92	116.2	0.8	55.9	0.4
2.11	1.83	116.6	0.8	56.1	0.4
2.16	1.75	119.2	0.8	57.4	0.4
2.21	1.68	118.6	0.8	57.0	0.4
2.25	1.61	121.7	0.8	58.6	0.4
2.30	1.54	122.1	0.8	58.8	0.4

TABLE II - Cont.

λ(Å)	E(eV)	σ_T(barns/mol.)	$\epsilon(\sigma_T)$	σ_s/H(barns/H)	$\epsilon(\sigma_s/H)$
2.35	1.48	-	-	-	-
2.40	1.42	127.4	1.0	61.4	0.5
2.44	1.37	127.0	0.9	61.2	0.5
2.49	1.32	131.3	1.0	63.3	0.5
2.54	1.27	131.2	1.0	63.3	0.5
2.59	1.22	131.6	1.1	63.5	0.5
2.63	1.18	131.8	1.2	63.6	0.6
2.68	1.14	133.5	1.3	64.4	0.7
2.73	1.10	136.4	1.3	65.8	0.7
2.78	1.05	138.3	1.3	66.8	0.7
2.82	1.02	137.2	1.3	66.2	0.7
2.87	9.91×10^{-3}	140.4	1.3	67.8	0.6
2.92	9.59	140.7	1.2	68.0	0.6
2.97	9.28	144.3	1.3	69.8	0.6
3.01	8.99	143.7	1.4	69.4	0.7
3.06	8.71	144.0	1.4	69.6	0.7
3.11	8.45	147.8	1.5	71.5	0.7
3.16	8.20	143.1	1.4	69.3	0.7
3.21	7.96	145.4	1.4	70.2	0.7
3.25	7.72	147.6	1.4	71.3	0.7
3.30	7.50	148.1	1.4	71.6	0.7
3.35	7.29	149.9	1.4	72.5	0.7
3.40	7.09	150.5	1.4	72.8	0.7
3.44	6.89	150.6	1.4	72.8	0.7
3.49	6.71	153.6	1.5	74.3	0.7
3.54	6.53	152.4	1.5	73.7	0.8
3.59	6.36	154.7	1.6	74.9	0.8
3.63	6.19	157.0	1.6	76.0	0.8
3.68	6.03	157.6	1.6	76.3	0.8
3.73	5.88	157.6	1.7	76.2	0.8
3.77	5.73	155.8	1.7	75.3	0.9
3.82	5.59	157.8	1.8	76.3	0.9
3.87	5.45	161.4	1.8	78.1	0.9
3.92	5.32	159.5	1.9	77.2	0.9

TABLE II - cont.

λ(Å)	E(eV)	σ_T(barns/mol.)	$\epsilon(\sigma_T)$	σ_s/H(barns/H)	$\epsilon(\sigma_s/H)$
3.97	5.20	164.0	2.0	79.4	1.0
4.01	5.07	162.9	2.1	78.9	1.0
4.06	4.96	162.7	2.1	78.7	1.0
4.11	4.84	163.6	2.0	79.2	1.0
4.16	4.73	167.1	2.1	81.0	1.0
4.20	4.62	162.6	2.1	78.7	1.0
4.25	4.52	166.2	2.1	80.5	1.1
4.30	4.42	167.0	2.2	80.8	1.1
4.35	4.33	170.1	2.3	82.4	1.1
4.39	4.23	167.2	2.3	80.9	1.2
4.42	4.14	169.8	2.4	82.2	1.2
4.49	4.06	169.2	2.5	81.9	1.2
4.54	3.97	169.2	2.6	81.9	1.3
4.58	3.89	173.1	2.8	83.9	1.4
4.63	3.81	171.6	3.0	83.1	1.5
4.68	3.73	173.4	3.0	84.0	1.5
4.73	3.66	171.9	2.9	83.2	1.5
4.77	3.58	176.5	3.0	85.6	1.5
4.82	3.51	179.5	3.2	87.0	1.6
4.84	3.49	178.8	0.9	86.7	0.4
4.93	3.37	179.8	0.9	87.4	0.4
5.01	3.26	179.5	0.9	87.0	0.4
5.10	3.15	181.4	1.0	87.9	0.5
5.18	3.05	182.6	1.0	88.5	0.5
5.26	2.95	184.0	1.1	89.2	0.5
5.35	2.86	185.3	1.1	89.8	0.5
5.43	2.77	185.8	1.2	90.0	0.6
5.52	2.69	186.6	1.2	90.5	0.6
5.60	2.60	188.4	1.3	91.3	0.6
5.69	2.53	188.8	1.4	91.1	0.7
5.77	2.46	189.3	1.4	91.7	0.7
5.86	2.38	191.3	1.5	92.7	0.7
5.94	2.32	194.1	1.5	94.1	0.7
6.02	2.25	192.5	0.7	93.3	0.3

TABLE II - cont.

λ(Å)	E(eV)	σ_T(barns/mol.)	$\epsilon(\sigma_T)$	σ_s/H(barns/H)	$\epsilon(\sigma_s/H)$
6.11	2.19	193.7	0.7	93.9	0.3
6.19	2.13	197.2	0.8	95.6	0.4
6.28	2.07	197.6	0.8	95.8	0.4
6.36	2.02	198.2	0.8	96.1	0.4
6.45	1.97	199.9	0.9	96.9	0.4
6.53	1.91	201.0	0.9	97.4	0.4
6.62	1.87	200.4	1.0	97.2	0.5
6.70	1.82	204.2	1.0	99.0	0.5
6.79	1.77	204.5	1.1	99.1	0.5
6.88	1.73	204.9	1.1	99.4	0.5
6.96	1.69	205.8	1.2	99.7	0.6
7.05	1.65	207.4	1.2	100.5	0.6
7.13	1.61	211.6	1.3	102.6	0.6
7.22	1.57	208.2	1.3	101.1	0.6
7.30	1.53	211.2	1.4	102.4	0.7
7.38	1.50	213.8	1.5	103.7	0.7
7.47	1.46	213.4	1.5	103.5	0.7
7.56	1.43	216.6	1.6	105.0	0.8
7.64	1.40	213.4	1.7	103.4	0.8
7.73	1.37	217.8	1.8	105.6	0.9
7.82	1.34	220.9	1.9	107.2	0.9
7.90	1.31	221.8	1.9	107.6	0.9
7.99	1.28	223.4	2.0	108.3	1.0
8.07	1.25	225.3	2.3	109.3	1.1
8.16	1.23	224.9	2.4	109.1	1.2
8.24	1.20	228.2	2.5	110.7	1.2
8.33	1.18	229.0	2.7	111.1	1.3
8.41	1.15	229.1	2.8	111.2	1.4
8.50	1.13	229.4	3.0	111.3	1.5
8.59	1.11	228.6	3.2	110.9	1.6
8.67	1.09	232.5	3.4	112.8	1.7
8.76	1.07	234.6	3.7	113.8	1.8
8.84	1.04	234.0	3.8	113.5	1.9
8.93	1.02	230.8	3.9	111.9	1.9

TABLE II - cont.

λ(Å)	E(eV)	σ_T(barns/mol.)	$\epsilon(\sigma_T)$	σ_s/H(barns/H)	$\epsilon(\sigma_s/H)$
9.01	1.01	231.3	4.2	112.2	2.1
9.10	9.88×10^{-4}	234.8	4.7	113.9	2.3
9.18	9.69	239.8	4.8	116.4	2.4
9.27	9.51	232.5	5.1	112.7	2.5
9.36	9.34	244.2	5.6	118.6	2.8
9.44	9.17	233.7	6.0	113.3	3.0
9.53	9.01	233.2	6.3	113.0	3.1
9.61	8.85	249.5	7.6	121.1	3.8
9.70	8.69	248.4	7.8	120.6	3.9
9.78	8.54	250.6	8.9	121.7	4.4
9.87	8.40	248.3	9.5	120.5	4.7
9.95	8.25	24[illegible].6	9.3	117.6	4.6

TABLE III

TOTAL NEUTRON CROSS-SECTIONS OF H_2O

E(eV)	λ(Å)	EXPERIMENTAL DATA (barns)[a]			CALCULATED VALUES (barns)				
		BNL-325 2nd ed. Suppl. 2 (1964)	GA-7581 (1966)	Present Experiment	McMurry-Russel	Nelkin	Nelkin presented[b] by Koppel-Young	Koppel-Young[c]	Free Gas
0.002	6.39	196		197	202	210	224	206	212
0.005	4.04	163	161.1	163	166	165	174	165	143
0.025	1.81	103	108.1	105	107	106	105	105	86.2
0.050	1.28	80	84.2	82	82.0	77.7	79	82	76.7
0.100	0.90	68	70.3	70	67.3	69.1	70	72	67.1
0.150	0.74	61	63.1		61.0	62.3	64	64	62.4

(a) Absorption was subtracted from total cross section data.

(b) Nucl.Sci.Eng. 19(1964) 412; scattering by oxygen was not included; the bound atom cross-section of 4 barns has been added to give corrected values.

(c) Includes anisotropy of vibrations; scattering by oxygen is not calculated; the bound atom cross-section of 4 barns has been added to give corrected values.

TABLE IV

CROSS-SECTION SLOPES OF THE CURVES σ_s/H vs. λ IN THE SUBTHERMAL REGION

SUBSTANCE	WAVELENGTH INTERVAL Å	SLOPE b_s barns/Å - H	REFERENCE
LIGHT WATER	4.8 - 9.9	6.8 ± 0.1	Present Experiment
	6.1 - 11.3	6.1 ± 0.1	BNL Slow Chopper (11)
	4.0 - 11.0	6.2 ± 0.3	Rush, Leung and Taylor (10)
POLYETHYLENE	5.0 - 9.0	5.1 ± 0.1	Present Experiment
	4.0 - 11.0	5.0 ± 0.2	Leung (26)

RESUMO

Foi medida a seção de choque total do polietileno e da água leve para neutrons com energias no intervalo 0,3 eV a $8{,}2.10^{-4}$ eV, utilizando-se um espectrômetro de tempo de vôo e um espectrômetro de cristal. Essas medidas, em grande número e com boa precisão, representam uma contribuição para o melhor conhecimento da seção de choque desses materiais. Os resultados para o polietileno são comparados com cálculos baseados em diferentes hipóteses sobre a dinâmica molecular do polímero; os valores calculados por Kirouac et al (Trans. Amer. Nucl. Soc. 12, 672, 1969) concordam com nossos resultados também na região sub-térmica, onde havia uma discrepância entre os valores calculados e experimentais. Nossos resultados para a água concordam com medidas anteriores, tanto na região térmica como sub-térmica; na região térmica eles concordam também com valores calculados segundo os modelos de Kopper-Young e McMurray-Russell. Foram derivadas as inclinações das curvas de seção de choque de espalhamento por átomo de hidrogênio, em função do comprimento de onda de neutron, no intervalo de 4,8 Å a 10 Å.

RÉSUMÉ

On a mésuré la section efficace totale du polyethylene et de l'eau légère pour les neutrons avec energies dans l'interval 0.3 eV jusqu'a $8.2.10^{-4}$ eV, en utilizant um spectromètre à temps de vol et un spectromètre à cristal. Les mésures répresentent une amélioration pour la connaissance de la section efficace de ces materiaux. On compare les résultats pour le polyethylene avec les calcus fondés sur de differentes hypothèses sur la dynamique moléculaire du polymer; les valeurs calculées par Kirouac et al (Trans. Amer. Nucl. Soc. 12, 672, 1969) sont en bon accord avec nos résultats, aussi bien dans la région sous-thermique, oú il y avait une discrépance entre les valeurs calculées et expérimentalles. Nos résultats pour l'eau sont en bon accord avec les mésures précedentes, aussi bien la regions thermique comme sous-thermique; ils sont d'accord aussi avec les valeurs calculées par les modèles de Koppel-Young et McMurray-Russel dans la region thermique. On a dérivé les inclinations des courbes de section efficace de diffusion par atome d'hydrogène en function de la longueur d'onde du neutron, dans l'interval de 4,8 Å jusqu'a 10 Å.

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