Report CF-599

Metallurgical Project

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FINAL REPORT ON

THE SCATTERING CROSS SECTION OF HYDROGEN AND THE CROSS SECTION OF CARBON FOR NEUTRONS OF ENERGIES 0.35 TO 6.0 MEV.

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Minnesota Group

John H. Williams, Official Investigator

April 1943

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Abstract

Neutrons obtained from the Li (p,n), C (d,n) and D (d,n) reactions were scattered by cyclohexane, C_6H_{12}, and by carbon under conditions of good geometry. The value of σ_H obtained is in good agreement with theory. The value of σ_C shows an interesting resonance phenomenon.

This document has been reviewed and is determined to be
APPROVED FOR PUBLIC RELEASE.

Name/Title: Tammy Claiborne/ORNL TIO
Date: 12/07/2020

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SECRET

Following the technique outlined in our previous reports[1] we have scattered neutrons of a wide range of energies from various sizes and thicknesses of cyclohexane, C_6H_{12}, and carbon in the form of graphite.

As sources of neutrons we have used a thin, (~40 kv), Li target with bombarding protons of discrete energies from 2.10 to 2.68 Mev to obtain neutrons of energies 0.35 to .97 Mev. Deuteron bombardment of a thick carbon target[1] checked the results for neutrons of energy 1.0 $\pm$ .1 Mev and bombardment of a thin carbon target provided neutrons of energies 1.6 and 2.0 Mev. A differential technique[1] with thick heavy ice target s under deuteron bombardment served as neutron sources of energies 2.0 to 6.0 Mev. In this manner we have overlapped the various sources at 1.0 and 2.0 Mev and gained confidence in the energy value ascribed to the neutrons studied.

The neutrons from these sources were detected by counting the individual recoil protons in ionization chambers of various designs. For the energy region up to 1.0 Mev the recoils were obtained from methane at 60 lbs./in.^{2} in a 2.5 cm. diameter chamber 1.0 cm. deep. By a suitable choice of bias, it was found possible to exclude the detection of neutrons of energy 100 kev less than the energy under investigation. Since we are not sure that neutrons of energy less than 250 kev might not be present in the Li (p,n) spectrum[2] at higher bombarding proton energies even though the Li target is only 40 kv thick, this technique excluded them from contributing to our measurements.

The D, C and the D, D neutrons were detected by counting recoil protons from a thin paraffin radiator inside the front of an argon filled ionization chamber. Biases were selected to favor the neutron energy studied.

In all cases the observed transmissions were corrected for scattering of neutrons into the detector by the scatterer by assuming that the scattering was spherically symmetrical in a center of mass system of coordinates. The measurements of Kikuchi, et al,[3] make this assumption reasonable for the case of neutrons of energy approximately 2.5 Mev scattered by carbon. The results of Barschall and Kaimer[4] indicate that the assumption is also true for hydrogen. In all cases, the geometry is "good" and the corrections to the observed transmission are small. The actual geometry employed is shown in Table I where L in cm. is the distance between source and detector and L/2 is the distance from source to scatterer. The diameter of the scatterer and detector employed is also shown as S in cm. and D in cm. respectively. The transmission corrected for single spherically symmetrical scattering leads directly to a determination of the cross section. The thickness of the scatterer, X, was chosen to obtain a reasonable transmission and to exclude the necessity of corrections for multiple scattering

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The results of these measurements are listed in Table I and shown graphically in Figures 1 and 2. The last column of Table I lists the values of σ_H given by Bohm and Richman[5]. Their calculation assumed a potential function made up of a narrow deep square well and a wide shallow square tail of dimensions necessary to fit the value of the quadrapole moment of the deuteron and to give the proper values of ^1S scattering. The comparison between the experimental results and this theory is made in Figure 1 by the full line. The scattering cross-section calculated by Bohm and Richman on the basis of a simple square well is shown by the dotted curve in Figure 1.

An examination of these curves leads to the conclusion that the more complex shape for the potential function is to be preferred. The accuracy of the measurements is not sufficiently great to allow suggestions for further modification of the choice of well shape. It is, however, interesting to note that the measurements present experimental evidence that the over simplified square is not acceptable

A comparison between the present results and those of former workers[6,7] is only possible in the range from 2.4 to 2.9 Mev. The agreement is well within the statistical errors given by these authors.

Figure 2 shows the manner in which the total cross-section of carbon varies with neutron energy. A doublet state of C^{13} is seen to exist, the energy levels lying at 8.53 and 9.21 Mev above the ground state. The widths of these levels must be much less than that indicated in the figure because the differential thick target technique provides neutrons of from 100 to 300 kev total energy spread in the energy region between 3.0 and 5.0 Mev. Other investigators[6,7] values of σ_C for neutrons of energies 2.4 to 2.9 Mev are several per cent larger than ours. It is difficult to understand this minor disagreement except on the assumtion of heavy impurities in the carbon scatterers employed by these workers.

REFERENCES

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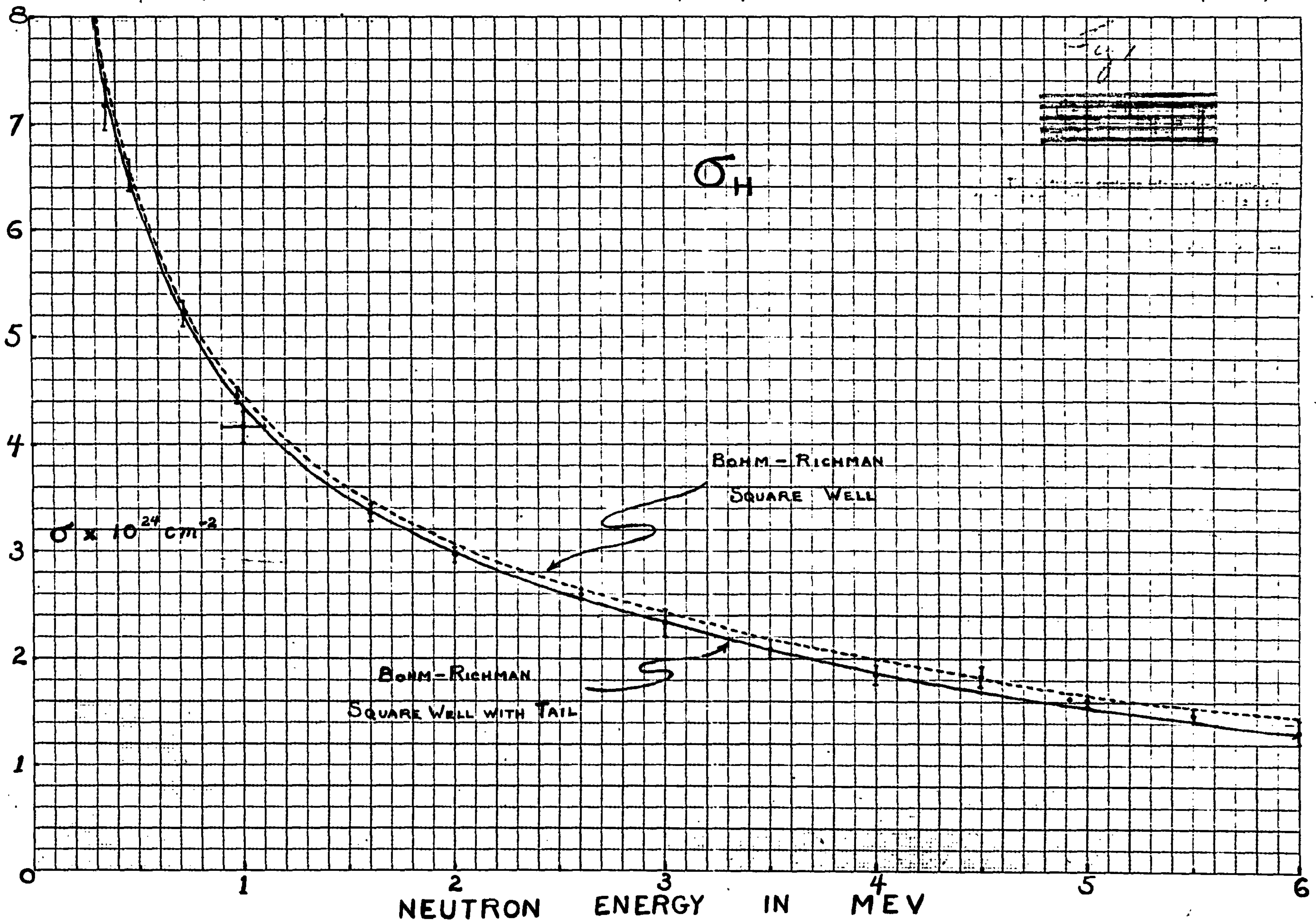
E_n	Observed Transmission C_6H_{12}	Observed Transmission C	L cm	S cm	D cm	X cm	Corrected Transmission C_6H_{12}	Corrected Transmission C	[redacted] $_6H_{12}$	σ_C	σ_H EXPT	σ_H THEORY
.35	.465		36	4.0	2.5	1.5	.442					
		.450	36	4.0	2.5	3.0		.444	[redacted]04.7 ± 2.8	3.15 ± .08	7.18 ± .24	7.33
.46	.490		36	4.0	2.5	1.5	.469					
		.450	36	4.0	2.5	3.0		.444	97.2 ± 1.68	3.15 ± .10	6.52 ± .15	6.43
.72	.553		36	4.0	2.5	1.5	.553					
		.532	36	4.0	2.5	3.0		.526	77.76 ± 1.38	2.49 ± .06	5.22 ± .12	5.21
.97	.594		36	4.0	2.5	1.5	.577					
		.547	36	4.0	2.5	3.0		.541	67.80 ± .78	2.40 ± .03	4.45 ± .08	4.43
1.0 ± [illegible]	.444		29	4.0	4.0	2.5	.408					
		.410	29	4.0	4.0	4.6		[illegible]	64.50 ± 1.68	2.38 ± .09	4.16 ± .15	4.35
1.6	.516,.321		40	4.0	4.0	2.5, 4.0	.500,.299					
		.484	40	4.0	4.0	4.6		.479	51.54 ± .96	1.90 ± .05	3.36 ± .08	3.38
2.0	.402		75	8.0	4.0	4.0	.364					
		.535	90	4.0	4.0	4.6		.534	45.30 ± .72	1.63 ± .04	2.96 ± .07	2.98
2.6	.433,.412		60	4.0	4.0	2.5, 4.0	.426,.403					
		.540	60	4.0	4.0	4.6		.538	40.86 ± .54	1.60 ± .03	2.60 ± .05	2.55
2.85		.607	60	8.0	4.0	4.12		.600		1.57 ± .11		
3.0	.445		50	4.0	4.0	4.0	.432					
		.520,.623	40,60	4.0,8.0	4.0	4.6,4.12		.515,.6[redacted]	37.56 ± 1.44	1.59 ± .08	2.33 ± .13	2.34
[redacted]								.578		1.69 ± .13		
3.5	.448		45	4.0	4.0	4.0	.434					
		.401,.464	45,64	4.0,8.0	4.0	4.6,4.12		.396,.4[redacted]	37.32 ± 1.50	2.39 ± .09	2.09 ± .09	2.09
3.75		.461	61	8.0	4.0	4.12		.452		2.43 ± .12		
4.0	.477		85	4.0	4.0	4.0	.474					
		.501,.550	85,58	4.0,8.0	4.0	4.6,4.12		.500,.5[redacted]	33.30 ± .90	1.85 ± .10	1.85 ± .09	1.87
4.25		.502	63	8.0	4.0	4.12		.494		2.16 ± .07		
4.5	.500		60	8.0	4.0	4.0	.472					
		.540	60	8.0	4,0	4.12		.532	33.60 ± 1.08	1.93 ± .06	1.83 ± .10	1.69
4.75		.598	95	8.0	4.0	4.12		.595		1.60 ± .15		
5.0	.561		85	8.0	4.0	4.0	.549					
		.685	85	8.0	4.0	4.12		.682	26.80 ± .60	1.18 ± .03	1.61 ± .05	1.54
5.5	.588		85	8.0	4.0	4.0	.577					
		.673	85	4.0	4.0	4.6		.672	24.18 ± .67	1.07 ± .04	1.48 ± .06	1.42
6.0	.608,.603		63,100	4.0,8.0	2.0,4.0	4.0	.605,.599					
		.698	100	8.0	4.0	4.12		.696	22.56 ± 1.32	1.11 ± .10	1.32 ± .12	1.31



σ_H
$\sigma \times 10^{24}\ cm^{-2}$
BOHM – RICHMAN
SQUARE WELL
BOHM – RICHMAN
SQUARE WELL WITH TAIL
NEUTRON ENERGY IN MEV
0
1
2
3
4
5
6
7
8

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