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TOTAL CROSS SECTIONS OF TRITIUM, HYDROGEN, AND HELIUM FOR FAST NEUTRONS

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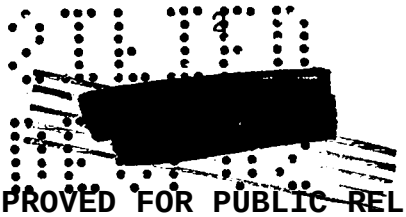

ABSTRACT

By using gaseous samples in neutron transmission experiments the total cross section of tritium has been measured over the energy region from 0.3 to 7.0 Mev and at the following additional energies: 14.1, 18.0, 19.1, and 20.0 Mev. A plot of cross section versus neutron energy shows a broad maximum with the greatest value of 2.5 barns at 3.7 Mev. Cross sections for helium were measured in the energy region from 1 to 3 Mev and for both hydrogen and helium at 14.1 Mev.

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INTRODUCTION

The set of measurements reported herein is an outgrowth of a program to measure, for use in weapon calculation, the total cross section of tritium for 14-Mev neutrons. After plans were completed for an experiment suitable to the hazards of handling large quantities of tritium, preliminary experiments on safe materials, viz., hydrogen and helium, were carried out to check the validity of the techniques and to gain experience in the hope of minimizing false moves in the subsequent measurements with tritium.

PROCEDURE

All samples were contained in gaseous form in steel cells 100 cm long and 1 in. outside diameter. The cell employed for hydrogen and for tritium was designed, fabricated, and pressure-tested by Group CMR-9[1], who also made accurate dimension and volume measurements and filled the cell with accurately measured quantities of gas. Data furnished by Group CMR-9 on gas weight and/or gas pressure, cell volume, and cell length were used to compute the number of atoms per cm^2 in the path of a neutron beam traversing the cell lengthwise. An identical evacuated cell was used to replace the gas-filled cell in the course of the measurements.

Group CMR-9 also furnished spectrographic analyses for the tritium and hydrogen samples. Table I gives the composition of filling No.

7 which is typical of the tritium samples. Filling No. 7 was retained in the cell for a long period of time and some of the cross section data were taken 6 months after the cell was filled. At the time of these final measurements 4 percent of the tritium had decayed to He^3. It was assumed in the analysis of the data that the He^3 and tritium cross sections are equal. Five percent hydrogen in the tritium samples contributed about 3 percent to the attentuation of the neutron beam, except at neutron energies below 1 Mev where the hydrogen contribution increased to 23 percent at the lowest neutron energy of 0.29 Mev.

Normal helium samples were contained in a different steel cell having a cylindrical wall of 1/32-in. thickness as compared with 1/16-in. thickness for the cell which held the tritium and hydrogen samples. The number of atoms per cm^2 of helium was determined from data on gas weight, cell volume, and cell length.

Table II lists the various gas fillings and the neutron energy regions for which they were used. Transmissions for 14-Mev neutrons when the cell was filled to 2000 psi were approximately 0.62, 0.59, and 0.72, respectively, for hydrogen, tritium, and helium.

In the geometry employed for the transmission measurements the neutron source and the neutron detector were spaced 30 cm from opposite ends of the 100-cm long cell. To get information as to the number of neutrons scattered into the detector by the long cylindrical cell wall, measurements were made with a dummy "cell" on which there were no end plates. Neutrons from the source were counted with and without the

dummy cell in place in the usual geometry. No in-scattering by the cell wall could be detected. In fact, the observed ratio of the count with dummy cell in place to the count without dummy cell was 0.996 ± 0.003 at 14-Mev neutron energy and 0.996 ± 0.003 at 2 Mev. Of course the cell wall may serve as a shield as well as a source of scattered neutrons. It is therefore possible that a small amount of in-scattering by the cell wall was compensated for by its shielding effect.

Calculations were made of the number of neutrons scattered into the detector by the gas sample. Though the calculated effect was less than experimental errors, corrections of 0.1 and 0.2 percent were added to the cross sections for hydrogen and tritium, respectively, in the case of the measurements at 14 Mev.

Neutron sources employed in the measurements were as follows: The reactions T(p,n), D(D,n), and T(D,n) with the electrostatic generator of Group P-9 gave neutrons in the respective energy intervals 0.3 to 3.0 Mev, 3.4 to 7.0 Mev, and 18 to 20 Mev. In each case the target material was contained as a gas in a small cell into which the beam entered through a thin window of aluminum or nickel. Neutrons emerging in the direction of the incident p or D beam were used in the experiments. The neutron energy spreads listed in Table III were computed from the thickness of the gas target. Neutrons of energy 14.10 Mev were obtained from the T(D,n) reaction with the 250 kv Cockcroft-Walton accelerator of Group P-4. Thick targets of tritium absorbed in zirconium were bombarded with 250 kev diatomic deuterium ions. The direction of observation

of the neutrons in this case was at an angle of 88° with respect to the deuteron beam.

For the experiments with the electrostatic generator the relative numbers of neutrons were monitored by means of a current integrator measuring the relative amount of beam incident on the target. In addition to the current integrator a long counter was employed as monitor for the case of neutrons from the T(p,n) reaction, and a hydrogen-filled proton recoil ionization chamber for neutrons from the D(D,n) reaction. For the experiments with the Cockcroft-Walton accelerator the number of neutrons was monitored by counting alpha particles from the T(D,n) reaction.

A variety of neutron detectors was employed in the transmission geometry. In the neutron energy region from 0.3 to 3.0 Mev a 1/2-in. diameter ionization chamber filled with hydrogen or deuterium (200 to 700 psi) was used. In the region from 3.4 to 7 Mev both the hydrogen-filled recoil chamber and a 1/2-in. diameter by 1-1/2-in. long stilbene crystal were used at different times. In the region from 18 to 20 Mev a 3/4-in. diameter by 1-1/2-in. long anthracene crystal was used. At 14 Mev the recoil chamber filled with 600 psi deuterium and 600 psi argon was employed.

In order to measure the background count arising from neutrons or gamma rays not originating in the target, a 25-in. long copper bar was inserted midway between neutron source and detector in the position alternatively occupied by the scattering sample. This bar was held in

place by a 100-cm long steel tube of the same type as that used in construction of the pressure cell. In the measurements at 14 Mev the background count was usually about 1 percent of the count observed without the bar. In the measurements at other neutron energies the background ranged from 1 to 4 percent.

A significant source of background neutrons was present in the measurements involving acceleration of deuterons in the electrostatic generator. Since these neutrons originated at points in line with the axis of the sample, and since they were in general not of the same energy as the principal neutron source, it was necessary to make a correction for their presence. The correction was made by filling the gas target cell with hydrogen instead of the usual target gas and making complete transmission measurements. Without the scattering sample in place the count with hydrogen in the target ranged from 2 to 5 percent of the count observed with the usual target gas. It is evident that this correction also eliminates any contribution arising from gamma ray sources at points along the path of the deuteron beam.

RESULTS

Table III tabulates all the measured cross sections along with estimated probable errors. The quoted errors are in general two to three times the statistical errors. In estimating the rather small errors quoted for hydrogen and tritium at 14 Mev, we have made use of the statistical error of $\pm$ 0.003 barn and an estimated error of $\pm$ 0.002 barn

due to uncertainty in the number of atoms per cm^2. Allowance has also been made for uncertainty in measurement of true background and for the uncertain influence of the long steel cell in spite of the fact that no scattering of neutrons by the cell wall could be detected in the geometry employed.

The present value obtained for hydrogen is in good agreement with the value 0.689 ± 0.005 barn at 14.10 ± 0.05 Mev reported by Poss, et al.[2] Good agreement between the observed helium cross sections with Wisconsin[3] measurements is also gratifying.

REFERENCES

1. Mills, Edeskuty, and Sesonske of Group CMR-9 prepared detailed reports giving quantitative data on the cell and gas fillings.

2. Poss, Salant, and Yuan, Phys. Rev. 87, 11 (1952).

3. Bashkin, Mooring, and Petree, Phys. Rev. 82, 378 (1951).

Table I

COMPOSITION OF TRITIUM SAMPLE IN FILLING NO. 7

The final composition was computed from the initial composition by using 12.5 years as the half-life for decay of tritium into He^3.

Isotope	Relative number of atoms	
	Initial (11/19/51)	Final (6/24/52)
T	94.9	91.0
H	4.9	4.9
D	0.15	0.15
He^3	0.05	4.0

Table II

CELL FILLINGS AND NEUTRON ENERGIES
AT WHICH MEASUREMENTS WERE MADE

Filling No.	Nominal gas pressure (psi)	Neutron energy (Mev)
1	2000 H_2	14.1
2	1500 H_2	14.1
3	2500 H_2	14.1
4	2000 T_2	14.1
6	2000 T_2	14.1
7	1000 T_2	0.3 to 20 (all)
8	1900 He	14.1
9	2000 He	14.1
10	1900 He	0.3 to 6.5

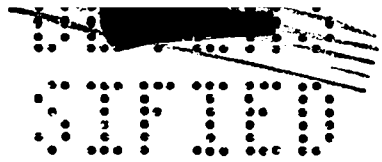


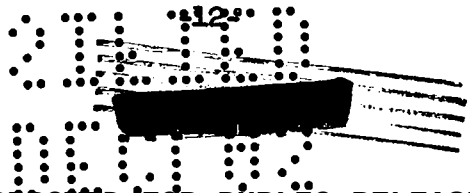
TABLE III

TOTAL NEUTRON CROSS SECTIONS

Neutron energy (Mev)	Neutron energy spread (Mev)	Tritium cross section (barns)
0.29	0.06	1.39 ± 0.07
0.54	0.05	1.57 ± 0.05
0.71	0.16	1.58 ± 0.05
0.99	0.15	1.69 ± 0.05
1.11	0.04	1.72 ± 0.05
1.50	0.12	1.89 ± 0.04
2.03	0.10	2.09 ± 0.04
2.49	0.09	2.28 ± 0.05
2.99	0.08	2.40 ± 0.05
3.4	1.26	2.43 ± 0.05
3.73	0.21	2.49 ± 0.05
4.1	0.82	2.40 ± 0.05
4.77	0.15	2.28 ± 0.05
4.80	0.47	2.28 ± 0.05
5.34	0.34	2.16 ± 0.04
5.52	0.19	2.17 ± 0.04
6.07	0.15	2.05 ± 0.04
6.58	0.15	1.90 ± 0.04
6.97	0.20	1.81 ± 0.04
14.10	0.06	0.978 ± 0.007
18.0	0.34	0.76 ± 0.04
19.1	0.21	0.76 ± 0.04
20.0	0.13	0.66 ± 0.04

Neutron energy (Mev)	Neutron energy spread (Mev)	Helium cross section (barns)	
0.94	0.15	6.31 ± 0.13	
1.50	0.12	5.62 ± 0.11	
1.98	0.10	3.98 ± 0.08	
2.49	0.09	3.16 ± 0.06	
2.99	0.08	2.79 ± 0.06	
4.10	0.82	2.43	these values
5.04	0.34	2.11	are upper
6.46	0.24	2.06	limits
14.10	0.06	1.03 ± 0.02	

Neutron energy (Mev)	Neutron energy spread (Mev)	Hydrogen cross section (barns)
14.10	0.06	0.687 ± 0.007



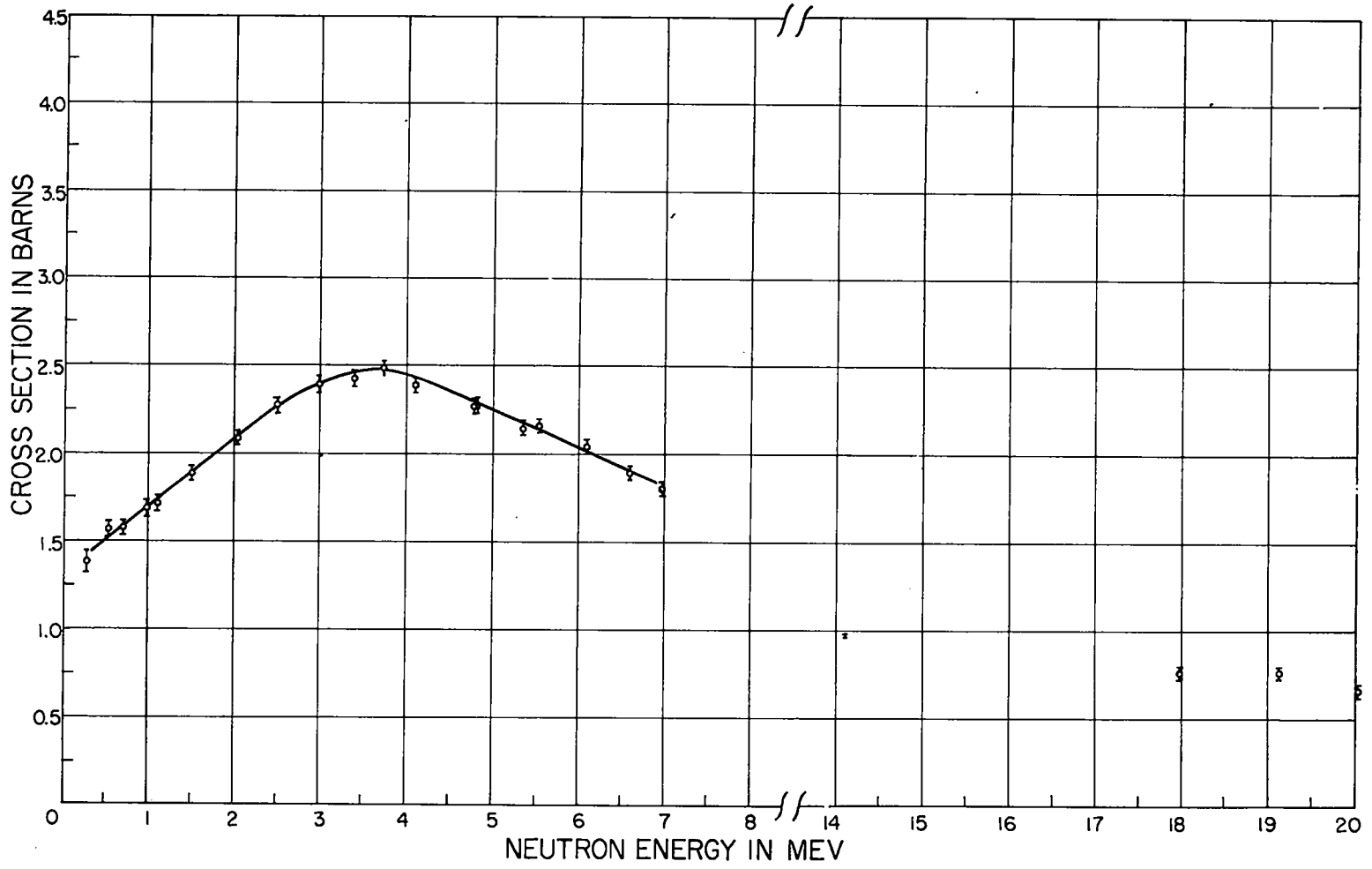


Fig. 1. Total neutron cross section of tritium vs neutron energy.

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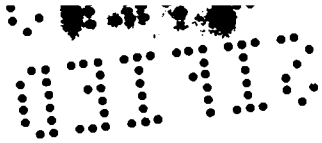

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