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Total Neutron Cross Section for Uranium From 20 Kev to 20 Mev

R. L. Henkel, L. Cranberg, G. A. Jarvis,
R. Nobles, J. E. Perry
Los Alamos Scientific Laboratory

ABSTRACT

The total neutron cross section of normal uranium has been measured for neutron energies from 20 kev to 7.6 Mev and at 17, 19 and 20 Mev. When combined with other published work in the 7-14 Mev range, the result is a smooth cross section curve up to 20 Mev. The curve fits smoothly on the surface showing total neutron cross section as a function of both atomic weight and neutron energy.

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Introduction

Although there had been some early measurements of the total neutron cross section for uranium^{1,2,3,4}, the results were mutually in disagreement well beyond the quoted statistical errors, and it therefore seemed desirable to repeat the work. The first recent measurements were made at Wisconsin⁵ and covered the neutron energy region up to 1.6 Mev. The present work repeated these measurements in better geometry, and considerably extended the energy range.

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- ¹J. H. Williams, University of Minnesota, Report, CP-507 (1943). *Private Comm.*
²H. H. Barschall, V. F. Weisskopf, Los Alamos Report, LA-169 (1944). *Private Comm.*
³W. H. Zinn, Argonne Progress Report, CP-2638 (1945). *Private Comm.*
⁴D. H. Frisch, Los Alamos Report, LA-256 (1945).
⁵Barschall, Adair, Bockelman, Graves, Henkel, Peterson, Los Alamos Report, LA-1060, (1950).
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Procedure

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The measurements were made at the large Van ~~der Graaff~~ generator at Los Alamos. The experimental area at this generator is located 20 feet above the ground and has a minimum amount of neutron scattering material nearby. This makes the room-scattered background smaller than is usually found at other laboratories. The experiment consisted of a good geometry transmission measurement in which samples of normal uranium were placed midway between the source of neutrons and a neutron detector. The samples were 1-inch diameter metallic uranium cylinders whose lengths were adjusted to give a neutron transmission of about 60%. The cross sections were calculated by assuming the usual exponential decrease of

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neutron intensity in the sample. Neutrons were obtained from the reactions $\text{Li}^7(\text{p},\text{n})\text{Be}^7$, $\text{T}(\text{p},\text{n})\text{He}^3$ and $\text{D}(\text{d},\text{n})\text{He}^3$, $\text{T}(\text{d},\text{n})\text{He}^4$. Since there was a spread in neutron energies caused by the finite target thickness and by straggling in the entrance foil of the gas targets, the effective neutron energy was taken to be the average neutron energy. The neutron energies were calculated from the known Q-values and dynamics of the various reactions.

The techniques and geometries varied considerably for the different neutron energy ranges. Many of the experimental details are given in Table I, wherein all items should be self explanatory except the definition of the background. The room-scattered background is caused by those neutrons which are scattered back into the detector by the floor, apparatus, etc. This background is measured by replacing the sample by an opaque shadow cone. The extraneous background is caused by neutrons released by deuterons which strike control slits, beam collimators, and target foils. It is measured by replacing the target gas by hydrogen and repeating all measurements. Miscellaneous additional details are given below.

Lithium layers were evaporated in high vacuum onto a .010-inch tantalum backing while in position on the proton beam tube. The evaporation was from a stainless steel furnace heated by an external radio frequency induction coil. Mirror-like lithium layers of controlled thickness were easily obtained. The target was designed so that it could be made to gyrate about the beam axis without the use of a rotating vacuum seal, and was cooled with air. Under these conditions both the neutron yield and the target thickness were stable with time. The target arrangement produced a point neutron source having a long life

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TABLE I

Experimental Conditions

Neutron energy range	20 Kev - 160 Kev	160 Kev - 3.8 Mev	4 - 7.6 Mev	17, 19, 20 Mev
Source reaction	$\text{Li}^7(p,n)\text{Be}^7$	$\text{T}(p,n)\text{He}^3$	$\text{D}(d,n)\text{He}^3$	$\text{T}(d,n)\text{He}^4$
Target	Evap Li	T_2 gas	D_2 gas	T_2 gas
Neutron angle	115°	0°	0°	0°
Neutron energy spread	15 Kev	40 - 20 Kev	200 Kev	200 Kev
Neutron detector	B^{10}F_3	H_2 recoil	H_2 recoil	Anthracene scintillator
Source detector separation	36 cm	58 cm	58 cm	144 cm
Scatterer cone	$\text{CH}_2\text{B}_4\text{C}$ cone	Polyethylene cone	Polyethylene cone	18" copper bar
Room scattered background correction	40%	1%	2%	1%
Extraneous background correction	0	0	.1%	2%
Gas target entrance foil		.0001" Al	.00005" Ni	.00005" Ni

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without the disadvantages of oil and carbon deposits on the lithium experienced with the earlier targets employing rotating seals.

The gas targets were contained in a cell 3 cm long. Protons for the $T(p,n)$ reaction entered the cell through a .0001" aluminum foil, but, because of the large $Al(d,n)$ yield, it was necessary to change to .00005" nickel foil for the DD and DT reactions. The boron trifluoride counter was similar to that described by Seagondollar⁶. It was essentially a scaled-down version of a long counter⁷, but with increased efficiency at low neutron energies. This counter was 2" in diameter by 5" long and was filled with about 32 psi of $B^{10}F_3$. The recoil counters had an active volume of 7/8" diameter by 3 inches long and were filled with purified hydrogen or helium at pressures up to 700 psi. For the 17, 19 and 20 Mev points the counting system utilizing anthracene scintillation counters was that developed by Coon, et al⁸, for their total cross section measurements at 14 Mev. The total cross section values obtained were independent of the type of counter used.

⁶L. W. Seagondollar and H. H. Barschall, Phys. Rev. 72, 439 (1947).

⁷A. O. Hanson and J. L. McKibben, Phys. Rev. 72, 673 (1947).

⁸J. H. Coon, E. R. Graves and H. H. Barschall, Phys. Rev. 88, 562 (1952).

Results

The data are presented in Figures 1 and 2. They show a smooth variation of cross section with energy. Although data were taken at 30 kev intervals between 200 kev and 3.8 Mev, these data shown in Figure 1 are averaged over 100 kev intervals since within statistical errors they

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were in agreement with the curve shown. The statistical errors for most points are less than ± 0.2 barn. The points plotted between 7 and 12 Mev are from the work of Hereson and Darden⁹ and the point at 14 Mev is from the work of Coon, et al.⁸ The squares in Figure 2 are the averaged data taken from the Wisconsin work.⁵ We have applied to all the present data an in-scattering correction of the form $\frac{10 \Delta \sigma}{\sigma} = \frac{1}{L} \left(\frac{D}{L} (kr + 1) \right)^2$, where L is the distance between the neutron source and the detector, D is the diameter of sample, k is the neutron wave number, and r is the nuclear radius given by $1.4 A^{1/3} \times 10^{-13}$ cm. The correction was appreciable (2-3.5%) only from 4-7 Mev.

⁹H. Hereson and S. Darden, Phys. Rev. 89, 775 (1953).

¹⁰R. B. Day and R. L. Henkel, Phys. Rev. (In press) (This formula is an approximate relation derived from Feld, et al in Final Report of the Fast Neutron Data Project, NYO-636 (1951).

Discussion

The present results do not agree with the early work^{1,2,3,4}, but do agree quite well with the work done by Barschall et al.⁵ The poorer geometry used in reference 5 (see ^{*}appendix) led to a 3% in-scattering correction which was made on the assumption of isotropic scattering. If neutron diffraction had been used as the basis for the in-scattering correction, the agreement with the present data would have been better for energies above 1 Mev.

Barschall¹¹ has shown that up to 3 Mev there is a regular pattern followed by the curves of total neutron cross section with neutron energy as one considers heavy nuclei of different atomic weight. Hereson⁹

^{*} Appendix here as footnote.

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finds a similar smooth variation with atomic weight for neutron energies up to 12 Mev. The present data for uranium seem to fit smoothly into this general pattern. Feshbach, Porter and Weisskopf¹² have been able to describe this behavior by their "cloudy crystal ball" theory which replaces the nucleus by a complex potential well. This simple model reproduces the main features of the cross section curves for neutron energies below 3 Mev. Higher energy calculations have not yet been published.

The authors are indebted to M. Walt for the design and construction of the high pressure proportional counters and the oscillating lithium target assembly used in the work. We wish also to thank J. H. Coon for the use of the neutron detecting system used for the high energy measurements.

Appendix

The Wisconsin measurements¹¹ were performed in the same manner as those described by Adair, et al.¹³. The $\text{Li}^7(p,n)\text{Be}^7$ reaction was used *Barschall, Rockelman, and Sala, Phys. Rev. 25, 1124 (1949)*

¹¹ H. H. Barschall, Phys. Rev. 86, 431 (1952).

¹² H. Feshbach, C. E. Porter and V. F. Weisskopf, Phys. Rev. 90, 166 (1953).

¹³ ~~Adair, Barschall, Rockelman and Sala, Phys. Rev. 72, 1124 (1949).~~

as the source of neutrons and a B^{10}F_3 counter served as the neutron detector. Cylindrical samples of uranium, 1 3/4 inch diameter, were placed in a geometry such that the cross section for neutrons scattered through angles greater than 20° was measured. The statistical errors of the data varied from ± 0.7 barns at lower energies to about ± 0.2 barns above 1 Mev. However, these data were subject to two appreciable systematic

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errors. First, an inscattering correction assuming isotropic scattering was applied to the data of this relatively poor geometry experiment, while diffraction scattering should have been considered at higher energies. This error resulted in lowering the value of the reported cross section. Second, because of the 430 Kev excited state in Be^7 , there is a second group of low energy neutrons for proton energies above 2.31 Mev (or ground state neutron energies greater than 650 Kev). The intensity of the second group is only about 5% of the main group^{14,15}. However, the presence of the low energy group reduced the effective neutron energy, and made the observed cross sections too large. These two systematic errors are in opposite directions, and the reported cross sections are probably accurate to 5%.

13-¹⁴ F. Ajsenberg and T. Lauritsen, Rev. of Mod. Phys. 24, 321 (1952).

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CAPTIONS

**Figure I - Total Neutron Cross Section for Uranium as a Function of
Neutron Energy.**

**Figure II - Total Neutron Cross Section for Uranium as a Function of
Neutron Energy.**

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