

## Absorption Cross Section of Boron for Thermal Neutrons

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The thermal neutron absorption cross section of boron of different origin has been determined by comparing the decay of the neutron flux from a water solution of the sample with the flux decay from the same volume of distilled water. The ratio of the two decay curves is a pure exponential, independent of slowing down and of the presence of harmonic modes. After application of small corrections the decay constant of the ratio curve gives directly the absorption cross section. The result for the Argonne-Brookhaven standard boron is  $764 \pm 3$  barns as compared to  $755 \pm 5$ ,  $749 \pm 4$ , and  $771 \pm 5$  barns obtained at Argonne, Brookhaven, and Harwell, respectively.

NEUTRON time-of-flight transmission measurements have shown that the capture cross section of boron for neutrons varies as  $1/v$ .<sup>1</sup> The constant of proportionality, stated as the cross section at the standard velocity 2200 m/sec, has been determined repeatedly,<sup>1-6</sup> but the spread of the results is much larger than is to be expected from the standard errors claimed by the authors. These discrepancies have been attributed to variations in the isotopic abundance,<sup>7</sup> impurities in the boron compounds, and the chemical analysis. A further source of error lies in the need to subtract the scattering cross section from the measured total cross section to obtain the capture cross section.<sup>5,6</sup>

In view of these discrepancies we have made a determination of the boron capture cross section by a new and independent method, which is simpler and probably capable of higher accuracy than the transmission method, and which is much less influenced by the scattering of the sample. In this method a burst of neutrons is produced in a homogeneous moderating material by a pulsed neutron source. The subsequent free decay of the neutron flux from the moderator is measured with BF<sub>3</sub>-counters and a time analyzer. Two decay measurements are made, the moderator being in one case distilled water and in the other an equal volume of a dilute solution of a boron compound. The experimental arrangement is identical with the one used for a study of the neutron diffusion parameters of water.<sup>8</sup>

The boron content of the solution was determined by titration with NaOH after addition of mannite. The NaOH used was calibrated against a known amount of cp grade borax, which had been allowed to assume the

normal crystal water content by recrystallization and subsequent storage for several days above a saturated solution of Ca(NO<sub>3</sub>)<sub>2</sub> in a desiccator.

Figure 1 shows typical decay curves obtained with distilled water and a borax solution. The curves are corrected for counting losses amounting to less than 2 percent for the first channels after the end of the neutron burst. The initial parts of the decay curves are not exponential because of the presence during the first time intervals of non-slowed-down neutrons and of harmonic modes in the neutron distribution.<sup>9</sup>

The neutron absorption in the dissolved boron compound will give rise to a factor  $\exp(-\Sigma n_i \sigma_i v t)$  in the expression for the decay of the neutron flux but will not otherwise influence the decay.  $\Sigma n_i \sigma_i$  is the macroscopic absorption cross section of the dissolved compound per unit volume of the solution. For a  $1/v$ -absorber the validity of the above statement is quite general and does not depend on the common approximations of neutron physics, such as diffusion theory or the one-group model. If we take the ratio of the two decay curves of Fig. 1 measured with and without a dissolved boron salt, we will thus expect to get a pure exponential curve. This is indeed shown by the dotted curve of the diagram, which is an exponential even during the initial time intervals, where the individual curves are not. From the decay constant,  $\Sigma n_i \sigma_i v$ , of the exponential ratio curve, and the chemical analysis, we can calculate directly the absorption cross section. Minor corrections—a few tenths of one percent—have to be applied for the influence of the scattering cross section of the boron compound and for small differences of the volume and temperature of the liquid in the two measurements. Repeated measurements were made by the new method with different boron compounds, different concentrations, and different amounts of liquid. The results are shown in Table I.

The length of the neutron burst was always 40  $\mu$ sec, and the channel width 10  $\mu$ sec. The repetition time was 400  $\mu$ sec, except for the measurements I-1 and I-2 where a shorter repetition time of 200  $\mu$ sec was used in the runs with the boron solution. This was done in an

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<sup>3</sup> Fermi, Marshall, and Marshall, Phys. Rev. **72**, 193 (1947).

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<sup>5</sup> Carter, Palevsky, Myers, and Hughes, Phys. Rev. **92**, 716 (1953).

<sup>6</sup> P. A. Egelstaff, Atomic Energy Research Establishment, Harwell, Report N/M 62, 1953 (unpublished).

<sup>7</sup> Thode, Macnamara, Lossing, and Collins, J. Am. Chem. Soc. **70**, 3008 (1948).

<sup>8</sup> G. von Dardel and N. G. Sjöstrand, Phys. Rev. **96**, 1245 (1954).

<sup>9</sup> G. von Dardel, Trans. Roy. Inst. Technol. Stockholm No. 75, (1954).

attempt to gain intensity. It was found, however, that the use of different repetition times influenced the shape of the neutron burst, so that the decay curves with different repetition time are not directly comparable. The results obtained in these measurements are therefore discarded in taking the mean, but they show that the result does not depend on the amount of the solution.

In order to investigate the influence of the scattering cross section on the results we also made measurements on strong solutions of the weakly absorbing substance  $\text{Na}_2\text{S}_2\text{O}_3$ . These measurements confirmed that the influence of the scattering of the solute was very small and could be calculated correctly from the scattering cross sections using diffusion theory, except for very concentrated solutions.

The statistical error of a typical measurement with a boron concentration of 1 g/l is 0.28 percent. The uncertainty of the various corrections is less than 0.1 percent. The random error in the chemical analysis as determined by repeated measurements of the same solution is 0.15 percent. The total random error is thus about 0.3 percent. In weaker solutions the error is somewhat larger than 0.3 percent as shown by the last column in Table I. The spread around the mean of different results for the same salt is in substantial agreement with the estimated random errors.

The major systematic uncertainty lies in the chemical analysis. Since good agreement was found when the same solution was analyzed by us and by Argonne and Harwell chemists, we estimate this systematic error to be as low as 0.3 percent.

The result  $764 \pm 3$  barns for salt II is somewhat higher than the values  $749 \pm 4$  barns obtained by Carter *et al.*<sup>5</sup> and  $755 \pm 5$  barns obtained by Hamer-mesh *et al.*,<sup>4</sup> using the same salt. On the other hand it is lower than the value  $771 \pm 5$  barns obtained for this

TABLE I. Experimental results.

Boron compound	No.	Volume of solution liters	Concentration of boron g/l	Cross section barns	Random error barns
I. Borax (cp grade, Kebo, Stockholm)	I-1	3.3	1	(770)	2.5
	I-2	2.5	1	(770)	2.5
	I-3	3.3	1	764	2.5
	I-4	2.5	0.5	761	6
			Weighted average Total standard error		763
				$\pm 3$	
II. Boric acid (Argonne <sup>a</sup> and Brookhaven <sup>b</sup> standard)	II-1	2.5	1	764	2.5
				Total standard error	$\pm 3$
III. Boric acid (cp grade, Coleman and Bell, Norwood, Ohio)	III-1	2.5	1	760	2.5
	III-2	2.5	1.5	759	2.4
	III-3	2.5	1	765	2.5
	III-4	2.5	0.5	748	6
	III-5	2.5	0.7	761	3.5
			Weighted average Total standard error		760.5
				$\pm 3$	

<sup>a</sup> See reference 4.  
<sup>b</sup> See reference 5.

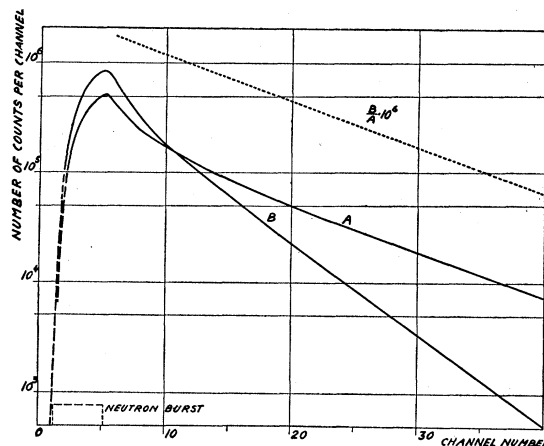


FIG. 1. Experimental decay curves for measurement I-3. Curve A was measured with distilled water, and curve B with borax solution. Measuring times were 2 and 4 hours respectively.

salt from the measured cross section of the Harwell standard boron,  $782 \pm 5$  barn,<sup>6</sup> and the ratio  $0.986 \pm 0.003$  between the Harwell and Argonne boron<sup>10</sup> measured with a pile oscillator.

Salt I has been compared at Argonne<sup>11</sup> and Harwell<sup>10</sup> with salt II by means of a pile oscillator method, and the values  $0.991 \pm 0.005$  and  $0.997 \pm 0.004$  were obtained for the ratio between the boron cross section in salt I and II. The latter value is in excellent agreement with the ratio  $0.999 \pm 0.004$  of our experimental results.

The cross section of salt I has previously been measured by von Dardel and Waltner,<sup>12</sup> who obtained a value of  $708 \pm 12$  barns using a pulsed method in a large geometry. As discussed elsewhere<sup>8</sup> in connection with the neutron-proton cross section, we believe the discrepancy to be due to the possible presence in the large geometry experiment of a probably time-dependent neutron background, for which an accurate correction could not be applied.

A method very similar to ours was used independently by Scott, Thomson, and Wright<sup>13</sup> to determine the cross section of a California-mined boron. Their result,  $744 \pm 20$  barns, is in agreement with ours though of lower accuracy. In their treatment of the data it has to be assumed that the decay curves are pure exponentials, and the result would be influenced by the presence of harmonic modes and fast neutrons, which distort the decay curves. With the refinements described in the present article the lifetime method of measuring thermal neutron cross sections should compete favorably in accuracy with other methods, such as the pile oscillator or slow chopper.

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<sup>10</sup> D. Littler (private communication).

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<sup>12</sup> G. von Dardel and A. W. Waltner, Phys. Rev. **91**, 1284 (1953).

<sup>13</sup> Scott, Thomson, and Wright, Phys. Rev. **95**, 582 (1954).