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PRODUCTION OF LOW ENERGY NEUTRONS BY FILTERING THROUGH GRAPHITE

By Herbert L. Anderson, Enrico Fermi, and Leona Marshall

A simple method to produce a beam of neutrons having average energy much lower than that corresponding to room temperature is described in this paper. The method consists in filtering ordinary thermal neutrons through a long and narrow block of graphite which, as will be shown, scatters out of the beam all the neutrons except those of very low energy.

On top of the graphite chain reacting pile which was constructed at the Argonne Laboratories, a graphite column was constructed with base 5 by 5 feet and 7 feet high. The column rose above the pile through a hole in the shield which covers the whole of the chain reacting pile. In such a column, the fast neutrons emitted by the pile are slowed down in the lower part of the column so that predominantly, only thermal neutrons diffuse upward in the column. Thermal neutrons purified to a high degree from higher energy neutrons are obtained in this way.

Attempts were made to measure the cross section of boron for neutrons emerging from the top of this column. We obtained 867×10^{-24} cm^2/atom, a result considerably greater than the value 770×10^{-24} cm^2/atom when a somewhat shorter column was used. These results indicated that lower energy neutrons penetrate more readily through large thicknesses of graphite than do the neutrons in the upper energy part of the Maxwell distribution.

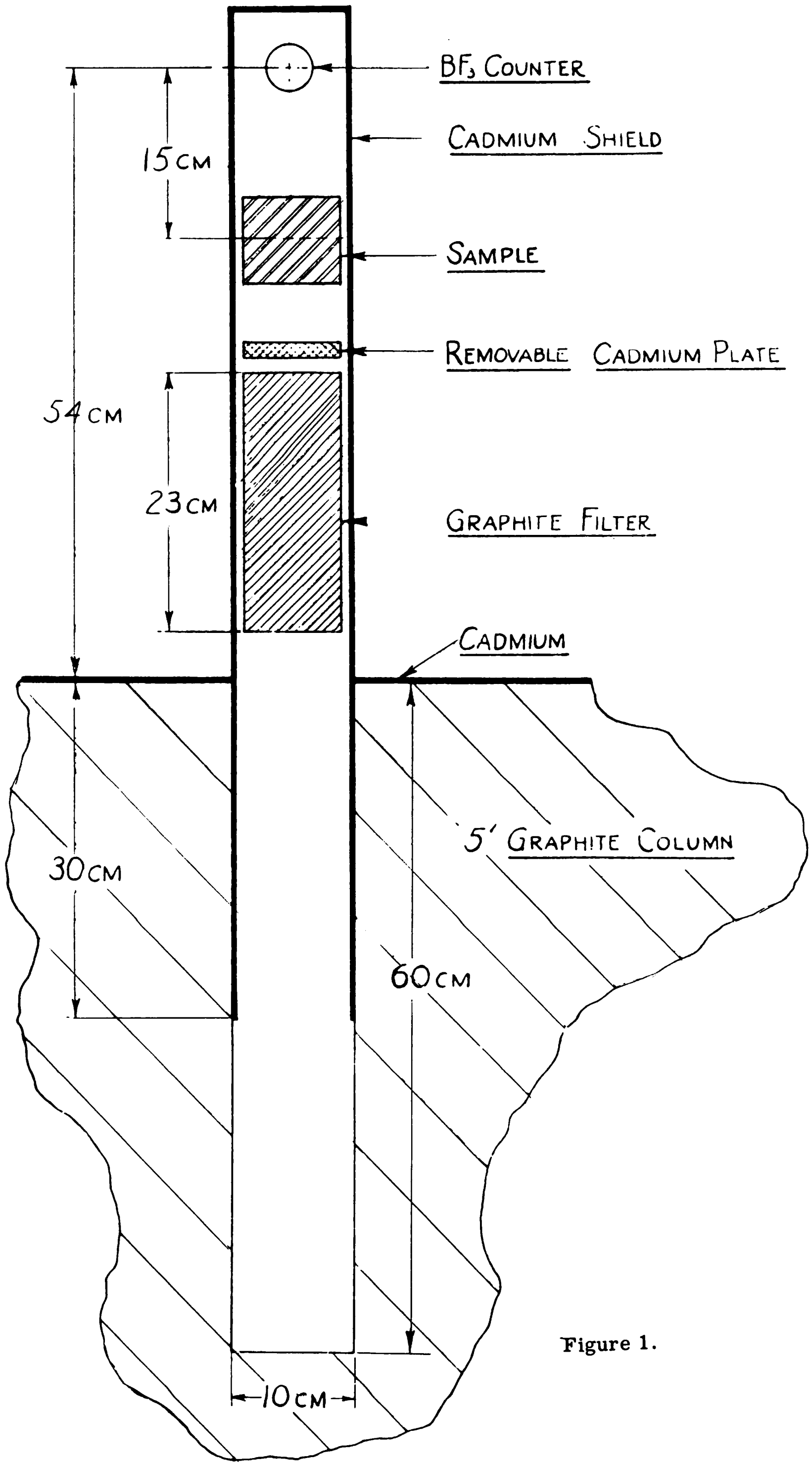
In order to investigate this effect in a more systematic way a good beam geometry was set up as shown in Figure 1. To increase the intensity and yet maintain good collimation, the neutrons used were those emitted from the lower part of a hole extending two feet down in the graphite thermal column. The neutrons could pass through a graphite filter (which was removable) and then through the sample, whose transmission it was desired to measure, and finally to a BF_3 proportional counter used as a detector. The whole assembly was isolated from stray thermal neutrons by the cadmium shield. A cadmium plate could be inserted above the graphite filter in order to measure the background. In all measurements the small background observed with this cadmium plate in place was always subtracted.

Measurements, by the transmission method, were made of the total cross sections of a number of substances with and without the 23 cm long graphite filter. The results are given in Table 1.

The first column gives the sample, the second, its thickness in grams/cm^2, the third and fourth columns give the logarithm of the transmission and the total cross section σ in units of 10^{-24} cm^2/atom obtained without the filter, while the fifth and sixth columns give the same quantities for neutrons which were filtered through 23 cm of graphite.

The marked decrease in the scattering cross section of graphite from 4.05×10^{-24} cm^2/atom to the value 0.70×10^{-24} cm^2/atom is quite striking. With the filter, the log of the transmission of the pyrex plates (boron) increase by a factor of 3.5. This corresponds to a reduction of energy by a factor of more than 12 for the neutrons which emerge from the graphite filter.

Since graphite is a polycrystalline material, Bragg reflection scatters all neutrons whose wavelength is smaller than the two times the largest lattice spacing.[1] The low energy neutrons are transmitted through the filter because their wavelength is larger than the largest lattice spacing in graphite crystals. Interference takes place in all directions, except the straight through direction for such neutrons.



BF3 COUNTER
CADMIUM SHIELD
15 CM
SAMPLE
REMOVABLE CADMIUM PLATE
54 CM
23 CM
GRAPHITE FILTER
CADMIUM
5' GRAPHITE COLUMN
30 CM
60 CM
10 CM

Figure 1.

Table 1. Transmission of filtered neutrons.

Substance	gm/cm^2	No filter: Log transmission	No filter: σ in 10^{-24} cm^2/atom	23 cm graphite filter: Log transmission	23 cm graphite filter: σ in 10^{-24} cm^2/atom
C (Graphite)	12.96	2.639	4.05	.453	.70
Pyrex	.241	.437		1.537	
Be	4.52	.977	3.25	.219	.73
Be	9.04	1.693	2.82	.424	.71
$\frac{1}{2}D_2O$	4.352	2.008	7.65	2.475	9.44
$\frac{1}{2}H_2O$	.455			2.61	85.8
$\frac{1}{2}H_2O$	.265			1.461	82.5
Bi	76.39	1.469	6.68	.226	1.03
S crystalline	19.91	.617	1.66	1.08	2.89
S amorphous	8.02	.530	3.52	1.063	7.06
S amorphous (next day)	8.02			.497	3.31

A calibration of the pyrex plates used in these experiments was carried out by E. Bragdon, E. Fermi, J. Marshall and L. Marshall, who determined their transmission as a function of neutron velocity using a mechanical velocity selector. In order to obtain the average velocity of neutrons by a measurement of transmission in boron, some assumption has to be made about the velocity distribution of the neutrons, in order to take into account the hardening of the beam in its transmission through the pyrex plate. For the neutrons emerging from the hole in the graphite column, a Maxwell distribution may be assumed and the correction for hardening can be made using the Bethe[2] correction. In this way we found that the kT energy of the neutrons from the hole was 0.023 ev, about 10 per cent less than that which corresponds to room temperature. The difference being due presumably to a partial filtering of the neutrons coming from the hole.

For the neutrons which filtered through 23 cm of graphite, the transmission data with the pyrex plate gave an effective neutron velocity of 533 meters per second. This corresponds to an effective neutron wavelength of 7.15 A°. By effective wavelength, we mean the wavelength we would measure if all the neutrons had the same velocity. For graphite, the largest Bragg wavelength is 6.69 A°. Our result for the effective wavelength is higher than this because of the contribution of the low energy tail of the Maxwell distribution. With a longer filter, we obtained an even larger effective wavelength which showed that for our 23 cm filter, the filtering was not yet complete.

Similar crystal effects were observed in Be and also in Bi, in spite of the fact that both atoms have a nuclear spin different from zero.

In the case of water, the fourfold increase in the cross section over the value[3] 21 x 10^{-24} cm^2 measured at 1.44 ev (indium resonance) was observed as was to be expected from the effects of chemical binding.[4] The effect of chemical binding is, presumably, also responsible for the increase in the cross section of D_2O.

Sulphur proved interesting. Sulphur prepared in the amorphous state gave a cross section of 7.06×10^{-24} cm^2 for the filtered neutrons, a value twice as high as the value obtained for the same sample with the unfiltered thermal neutrons. This increase is believed due to the cooperative scattering in aggregates of sulphur atoms, with dimensions small compared to the neutron wavelength. In such aggregates of n atoms, the scattering is proportional to n^2 rather than to n. The next day the same specimen, having partially crystallized, showed a smaller cross section.

To show the effects of the thermal motion of the atoms in a crystal on the interference conditions, the scattering cross section for 15.4 gm/cm^2 of graphite was studied with filtered neutrons as a function of temperature of the scatterer. The scatterer was heated with an oxy-acetylene torch and the temperature measured, using a thermocouple. Temperature equilibrium was not perfectly established in these experiments but the effect is evident. The results are given in Table 2.

Table 2. Temperature effect on the scattering of filtered neutrons by graphite.

Temp. of scatterer °C.	Total cross section in 10^{-24} cm^2/atom
20	.71
69	.84
117	.97
254	1.33
370	1.92

These experiments show clearly that the thermal motion of the crystal atoms tends to destroy the interference conditions.

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