PHOTONEUTRON CROSS SECTION OF ^{2}D, Li, ^{6}Li AND Bi NEAR THRESHOLD

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ABSTRACT

The (γ,n) cross section of natural lithium, Li-6 and Bi have been determined, in the 5 to 10 MeV energy interval, using gamma rays produced by thermal neutron capture.

A comparison between the results obtained and that of other groups is made.

I. INTRODUCTION

The photodisintegration of Li, ^{6}Li and Bi has been measured by several groups using bremsstrahlung radiation from Betatrons(1-5). The results obtained are in general for energies above 10 MeV and do not give detailed information on the cross section near threshold.

In the experiments described in this paper γ rays produced by thermal neutron capture in various substances have been used to measure the (γ,n) reaction in these elements. The gamma ray energies span the 5 to 11 MeV interval which covers the threshold region.

The cross sections were determined by detecting the neutrons produced in the reactions.

The cross section of deuterium was measured because its theoretical value is well known and can be used to test the counter efficiency.

A comparison between our data for Li, ^{6}Li and Bi and data obtained by other groups is made as well as with some theoretical predictions.

II. EXPERIMENTAL PROCEDURE

The gamma rays used were produced in targets placed near the IEAR-1 reactor core. The thermal neutron flux incident in the target with the reactor power at 2 MeV was about 4 x 10" $n/cm^2/s$. Gamma fluxes of the order of $10^4 \gamma/cm^2/s$ were used in the experiments.

The gamma radiation obtained was collimated and filtered to prevent neutron contamination(6). A schematic drawing of the collimator can be seen in the fig. I.

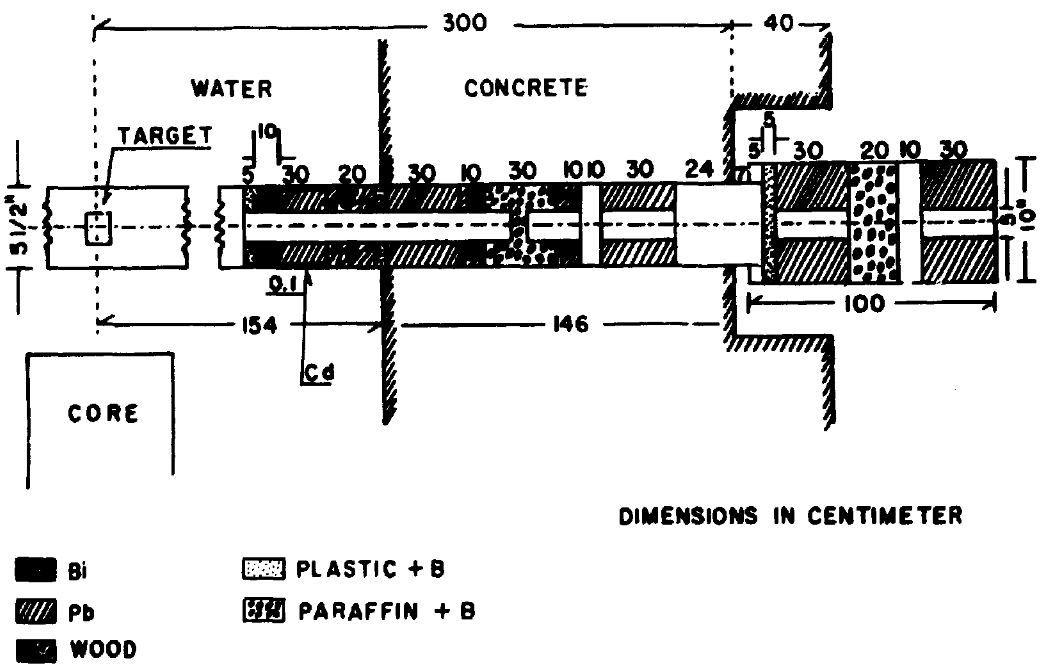

FIG. I - SCHEMATIC DIAGRAM OF THE COLLIMATOR

A box of Isopor, 13,5 cm thick, with water and a cadmium sheet 0.6 mm thick were used to remove from the beam the remaining neutrons. The target was placed in the beam at the center of a neutron counter system of the type Halpern[7]. This counter consisted of six BF_3 detector imbeded in paraffin, with their axes parallel to the direction of the γ-ray beam as shown in fig. II.

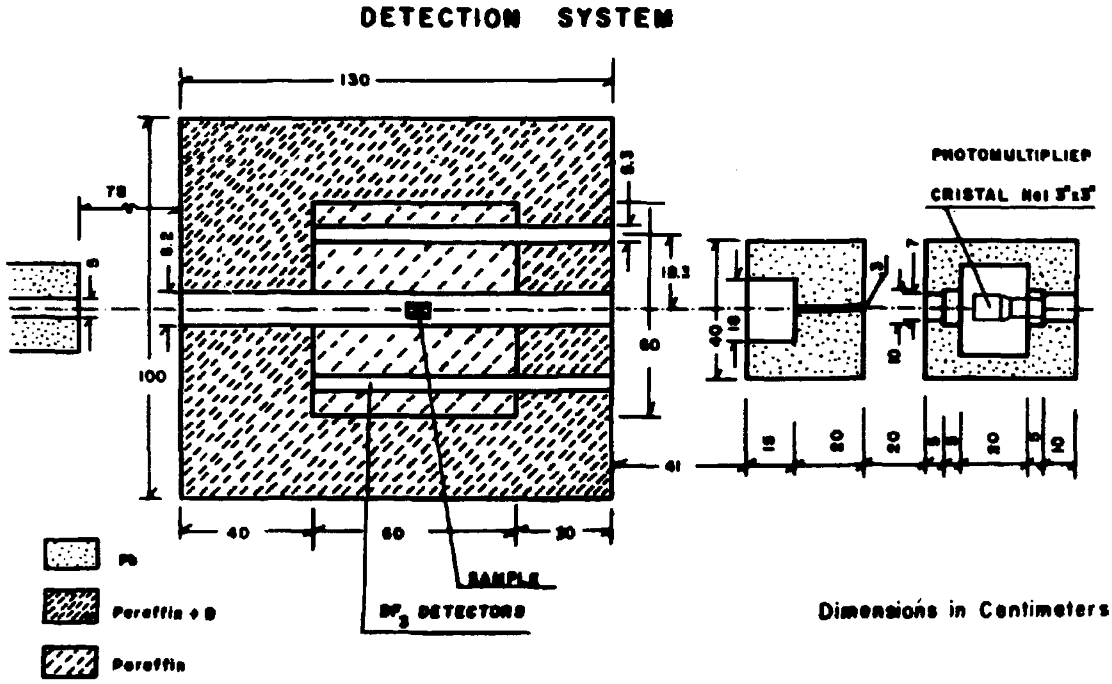

FIG. II - NEUTRON DETECTION SYSTEM

The amount of paraffin between the beam and the axes of the detectors was adjusted so that the efficiency of the system was approximatelly constant for a great interval of neutron energies. The efficiency of the counter was measured with a $^{24}Na+D_2O$ standard source, giving a value of 0.0377 ± 0.0022.

To monitor the γ-ray intensity a 3" x 3" NaI (Tl)crystal was used coupled to a 1024 channel pulse height analyser. A lead collimator of 1/4 inch of diameter, in front of the crystal insured that the beam struck the central part of the crystal.

Corrections were made for neutron self absorption in the target. The gamma ray intensity was also corrected for atenuation in the target.

III. EXPERIMENTAL DATA HANDLING

For each target the counts measured in the neutron detector system are due from several gamma lines. In general one of the γ lines is dominant.

The targets and lines used are in Table I.

TABLE I

TARGET	ENERGY (MeV)
S^{32}	5.43
Y^{89}	6.07
Ca^{41}	6.42
Ti^{49}	6.75
Be^{9}	6.82
Mn^{56}	7.16
Pb^{208}	7.38
Fe^{57}	7.63
Al^{28}	7.72
Zn^{65}	7.88
Cu^{64}	7.91
Ni^{59}	9.00
Cr^{54}	9.72
N^{15}	10.83

We have,

$$\frac{C}{\varepsilon NVI/S} = \sigma_1 + r_2\,\sigma_2 + r_3\,\sigma_3 + \ldots$$

where

I is the absolute gamma ray intensity obtained by integrating the counts under the photopeak

C is the neutron detector counts per second

r_i are the secondary lines intensity relative[10] to the principal ones

σ_i are the cross sections

ε is the system efficiency

N is the atom concentration of the target

V is the volume

S is the beam area

This last equation can be written for all targets and a linear system is obtained.

As some of the energies are not very different, approximations of the order of 50 keV have been made to reduce the system.

We have yet a greater number of σ_i (unknown quantities) than the number of equations, then we can obtain only a approxi - mated soluction for the cross sections which have therefore an error associated with them which is due to this analytical procedure[9].

IV. RESULTS

IV.1 DEUTERIUM

The target consisted of heavy water (D/D + H% = 99.75%). The agreement between our results and the theoretical values is very good (fig. III). This is a good check for the system efficiency and for calculations implied in solving the system of linear equations.

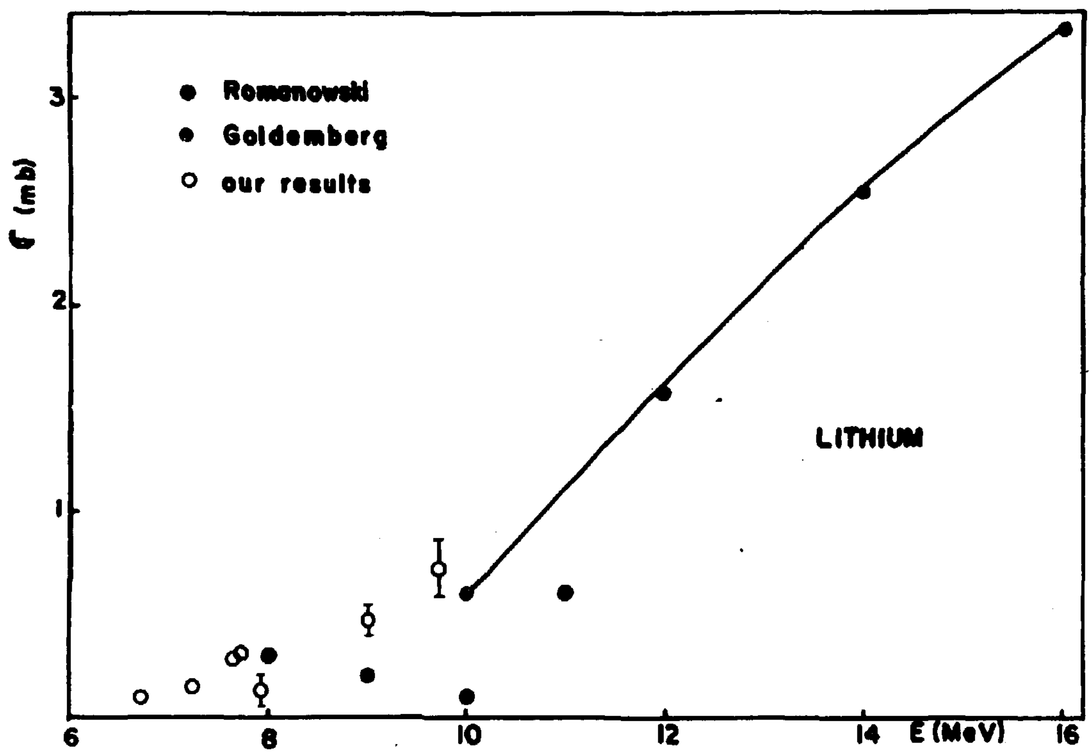

FIG. IV - NATURAL LITHIUM (γ,n) CROSS SECTION

IV.3 Lithium-6

The target used was of lithium carbonate enriched to 95.64%.

The cross section as a function of energy is plotted in fig. V. Some results of Romanowski and Voelker(2) and Green and Donahue(11) are also shown in the figure V. In general there is agreement between our results and that of Green and Donahue; these authors used also gamma rays produced by thermal neutrons capture (Table III).

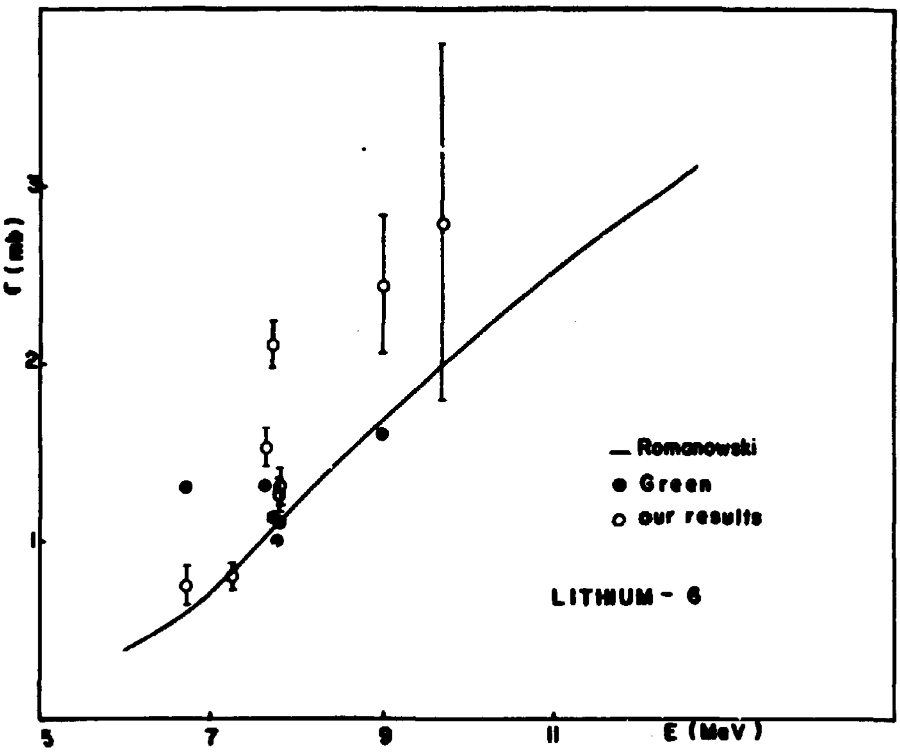

FIG. V - Li-6 (γ,n) Cross Section

TABLE III

Li-6 (γ,n) cross section

Energy (MeV)	σ(mb)	
	Our results	Green and Donahue
6.05	0.22 ± 0.03	-
6.73	0.75 ± 0.11	1.3 ± 0.2
7.23	0.80 ± 0.15	-
7.63	1.52 ± 0.20	1.3 ± 0.2
7.72	2.10 ± 0.26	1.13 ± 0.12
7.88	1.26 ± 0.18	1.0 ± 0.2
7.92	1.30 ± 0.19	1.1 ± 0.2
9.01	2.44 ± 0.34	1.6 ± 0.3

There is some indication of structure in our results, in particular the high point at 7.72 MeV.

IV.4 Bismuth

The cross section obtained by Montalberti, Katz and Goldemberg(3), Hust and Donahue(12), Halpern, Nathans and Mann(4), Harvey, Caldwell, Bramblett and Fultz(5) and our's are in fig. VI. One can see great discrepancies between them.

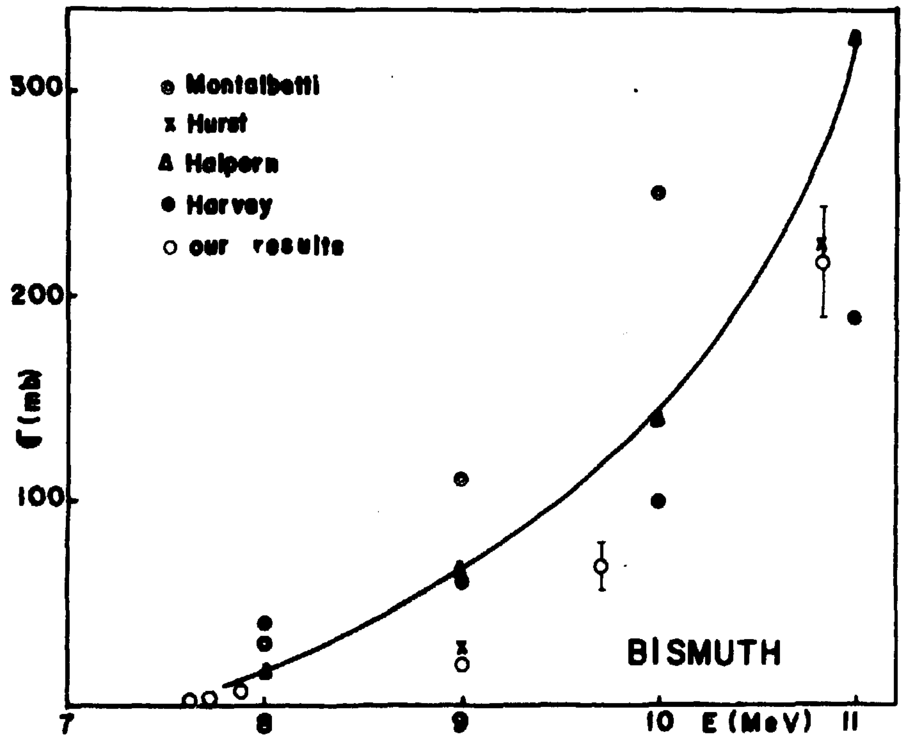

FIG. VI - BISMUTH (γ,n) CROSS SECTION

In the table VI our results are compared with that of Hurst and Donahue.

TABLE IV

Cross section (γ,n) of Bismuth

Energy (MeV)	σ (mb)	
	our results	Hurst and Donahue
7.63	2.5 ± 0.5	-
7.72	3.7 ± 0.5	-
7.88	7.0 ± 1.0	-
9.01	20.5 ± 2.6	36.1 ± 12.0
9.72	68 ± 11	-
10.83	217 ± 26	226 ± 27

The cross section for this nucleus exhibits no structure.

V. DISCUSSION

The photon absorption cross section of the nucleus is characterized by a giant resonance of 5 MeV width and the peak .. cross section at ~ 15 MeV.

The shape of the (γ,n) cross section in giant resonance region can be described by a single Lorentz line. The equation for the photon absorption cross section of a nucleus suggested by Axel[(13)] is

$$\sigma_a(E) = \frac{(1.3A/100\ \Gamma_g)\ E^2\ \Gamma_g^{\ 2}}{(E_R^{\ 2} - E^2)^2 + E^2\ \Gamma_g^{\ 2}} \quad \text{(mb)}$$

where

E - is the photon energy in MeV

E_R - the energy of the giant resonance in MeV-($E_R = 80A^{1/3}$)

Γ_g - the width of the giant resonance in MeV ($\Gamma_g = 5$ MeV)

A - the mass number of the target

A Lorentz curve as a discription for the giant resonance is a simplification and assumes that the giant resonance is due only to a dipolar interaction between the electromagnetic radiation and the nucleus.

This approximation was first checked for Hurst and Donahue[12].

The formula above gives the upper limit for the photon absorption cross section.

Our results have been compared with the prediction of Axel's formula in the case of Bi. The agreement at 10.83 MeV is good. For the lower energies our points are below the expected curve because near the (γ,n) threshold the (γ,γ) and (γ,γ') cross section compete strongly with the (γ,n) cross section and constitute an appreciable part of the absorption cross section.

RESUMO

Neste trabalho foram feitas medidas da secção de choque (γ,n) do Lítio, Li-6 e Bismuto usando-se radiação gama monocromática produzida por captura radioativa de nêutrons térmicos. Êsses raios gama têm energia no intervalo de 5 a 11 MeV.

Foi feita uma comparação com os dados obtidos por outros autores.

RESUMÉ

Dans ce travail on a fait des mesures de la section (γ,n) du lithium naturel, Li-6 et bismuth pour les energies de 5 a 11 Mev. On a utilisé la radiation gamma monochromatique produite par la capture radiative des neutrons thermiques.

Une comparaison a étée faite avec les résultats des autres anteurs.

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