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MEASUREMENT OF FAST NEUTRON ABSORPTION CROSS SECTIONS

T. S. BELANOVA

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The absorption cross sections for 25, 220 and 830-kev photoneutrons have been found for 20 elements, using neutron transmission in strict spherical geometry.*

1. METHOD OF MEASUREMENT.

FOR the measurement of neutron absorption cross sections, we used the transmission of neutrons in strict spherical geometry (with the neutron source placed inside a sphere of absorbing material). The spherical geometry of the experiment eliminates the direct effect of elastic scattering. The effect of inelastic scattering, which is important for high energy neutrons, was scarcely evident because a long counter was used for detecting the neutrons. Thus, from relative measurements we determined the absolute value of the neutron absorption cross section.

2. EXPERIMENTAL ARRANGEMENT

The experimental arrangement is shown schematically in the figure. Three photoneutron sources, spherical in shape, were used (Sb — Be, Na — D_2O, and Na — Be). They consisted of γ sources of Sb or NaF 25 — 30 mm in diameter, embedded in spherical targets of Be or D_2O, 8 mm in thickness. After assembly, the source had a diameter of 45 — 50 mm. Table I gives the characteristics of the neutron sources used in the present work.

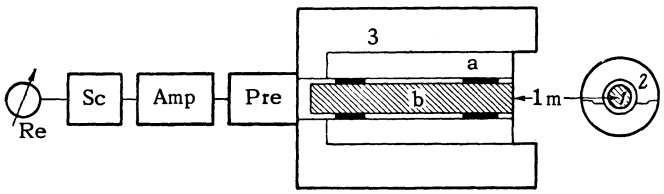

FIG. 1. Arrangement of the experiment. 1 — neutron source, 2 — absorbing sphere of sample material, 3 — long counter: a — paraffin container, b — boron counter; Pre — preamplifier, Amp — amplifier, Sc — scaler, Re — mechanical recorder.

The energy and intensity of the hard neutron group from the (Sb — Be) source was determined from the decay scheme[6] of Sb^{124} and the behavior of the (γ, n) reaction on beryllium.[7]

The samples of materials for study were in the form of spheres with outer diameter 15 — 22 cm, with a cavity 5 — 8 cm in diameter in their interior. They consisted of two hemispheres, so that the neutron source could be inserted into the cavity. The materials to be studied were taken both in cast metal and in powder form. The powders were placed in spherical brass containers having wall thickness 1 — 1.5 mm. The dimensions of the containers were the same as those of the cast spheres. The powders were thoroughly dried before filling the containers.

The neutron detector used was a long counter,[8]

*The measurements were carried out in 1952-1955.

TABLE I

Neutron source	Half-life	Angular distribution of neutrons from (γ, n) reaction	Maximum neutron energy	Average neutron energy, kev
(Sb—Be)	60 days	Isotropic[1]	29 kev[3]	25±4 (93%)[3,5] 400 (7%)
(Na—D_2O)	15 hr.	$1+4.7\sin^2\theta$[2]	270 kev[3,4]	220±20[3,4]
(Na—Be)	15 "	$1+0.8\sin^2\theta$[1]	1 Mev[3,4]	830±40[3,4]

which had the same sensitivity for neutrons of different energies. Pulses from the counter entered a wide-band amplifier and were counted in a PS-64 scale-of-64 recorder.

3. CALCULATION OF ABSORPTION CROSS SECTION

The computation was made using the formula

$$\sigma_a = \frac{(1-(N_2/N_1))\,(1-\exp\{-(R-r)/\lambda_{tr}\})}{[(R-r)\,(1-(N_2/N_1))+\bar{l}\,((N_2/N_1)-\exp\{-(R-r)/\lambda_{tr}\})]N_0}, \quad (1)$$

where σ_a is the neutron absorption cross section, N_0 the number of atoms per cc, λ_{tr} the transport length, $\bar{l}$ the mean length of neutron path in the material, N_1 the number of neutrons recorded from the (bare) neutron source, N_2 the number of neutrons recorded with the neutron source placed inside the absorbing sphere, R the radius of the sphere, and r the radius of the cavity in the sphere. The formula was obtained on the assumption that the path lengths of neutrons that suffer elastic scattering in the absorber have an exponential distribution. This formula is valid for relatively large absorptions $\sim 25-30\%$.

The average path of the neutrons for a point source was calculated using a somewhat modified formula due to O. D. Kazachkovskii,* which takes into account the presence of the cavity in the sphere:

$$\bar{l} = \frac{1}{2}\frac{R^2}{\lambda_{tr}} + 0.7R - \frac{3}{2}\frac{r^2}{\lambda_{tr}} + \frac{r^3}{r_0\lambda_{tr}} + 0.29\left(R-\frac{r}{2}\right)\exp\left\{-0.46\left(R-\frac{r}{2}\right)/\lambda_{tr}\right\}, \quad (2)$$

where $r_0 = R + 0.7\lambda_{tr}$. For some of the elements, $\bar{l}$ was computed using the data of Barshall et al.[9] on the transport cross section σ_{tr} for 220-kev neutrons, and the data of Lovchikova[10] for 830-kev neutrons. For most of the elements, at 830-kev, we used the values of σ_{tr} found by Walt and Barschall[11] and Walt[12] at 1 Mev. In those cases where there were no experimental data for σ_{tr} for the elements under investigation, we used the value of σ_{tr} computed on the basis of the paper of Feshbach and Weisskopf.[13] From the graphs in their paper, we found the ratio σ_{tr}/σ_{tot} (where σ_{tot} is the total cross section). Using the experimental values of σ_{tot}[14], we calculated σ_{tr} for all the elements studied. Comparison of known experimental values of σ_{tr} with the computed values showed satisfactory agreement.

For 25-kev neutrons the scattering is isotropic, and for low values of σ_a we can use the total scattering cross section $\sigma_s = \sigma_{tot}$ in place of σ_{tr} in calculating $\bar{l}$.

4. CONTROL EXPERIMENTS AND CORRECTIONS

1. Because the boron counter is sensitive to γ rays from the photoneutron source, a correction was made for counting of γ quanta. The correction was of the order of $2-3\%$ of the total count.

2. A correction for fission of U^{235}, which is contained in the normal mixture of isotopes, was made on the absorption cross section of uranium. Depending on the neutron energy, this correction amounted to $3-10\%$ of the capture cross section.

3. Elastic and inelastic slowing down of the neutrons in the spheres changes the primary neutron spectrum. This can result in a change in σ_a. Measurements were made with spheres of different sizes. The values of σ_a obtained were the same for a given element within the limits of accuracy of the experiment. This means that the softening of the initial neutron spectrum is of no consequence, in first approximation.

4. An experimental correction was made for scattering of neutrons in the walls of the sample holders. The size of this correction decreased from ~ 5 to 2% with increase of neutron energy from 25 to 830 kev. The capture cross section was calculated only for those powders in which the effect of capture was greater then the correction for the container.

5. In calculating the average neutron path length, it was necessary to include σ_a in determining σ_s from σ_{tot}. A method of successive

*Private communication.

approximations was used. We first determined σ_a using σ_{tot} in place of σ_s. Then we improved σ_s by using the formula

$$\sigma_s = \sigma_{tot} - \sigma_a$$

and again calculated σ_a. Since σ_{tot} is known to an accuracy of $\sim 15-20\%$, corrections of σ_s were made for those elements in which the measured $\sigma_a > 0.1$ barns.

6. A correction was made for the finite distance between the detector and the neutron source. This experimental correction was determined in several ways. For a distance of 1 meter between the detector and neutron source, the correction was of the order of 1% for all energies.

7. The presence of a hard neutron group in the (Sb — Be) source reduces somewhat the values of the measured absorption cross sections for 25-kev neutrons. A computation showed that σ_a is reduced by 3 — 5%. This correction was not applied to the experimental values of σ_a, since the size of the correction is beyond the limits of accuracy of the computation.

There were also other effects whose contribution to the computation of the absorption cross section were so small compared to the accuracy of the method that they could be neglected. Among these effects are:

(a) multiplication of the neutrons in U^{238} (< 1% correction to σ_a for uranium);

(b) the effect of the finite dimensions of the neutron source on the size of the average neutron path in the sphere (a correction of $\sim 1-2\%$ in $\bar{\ell}$);

(c) the effect of the anisotropy of the (γ, n) reaction in $(Na - D_2O)$ and (Na — Be) sources on the size of the average neutron path in the sphere (a correction of < 1% in $\bar{\ell}$);

(d) the effect of reduction of neutron energy because of backscattering in the source).

5. DISCUSSION OF RESULTS

The results of the present measurements are given in Table II. All the absorption cross sections reported up to now were measured mainly by the activation method.[14-18] They refer only to individual isotopes. The advantage of the method described here is that it does not require absolute measurements of neutron fluxes and β activity of samples, and is also applicable to isotopes which are stable after neutron capture. With the exception of a few isolated cases, the data of the present paper are in good agreement with the absorption cross sections found in the papers mentioned above.

The sensitivity of the long counter varies by

TABLE II

Element	σ_a, millibarn			Element	σ_a, millibarn		
	25±4 kev	220±20 kev	830±40 kev		25±4 kev	220±20 kev	830±40 kev
Mg	19±3	13±10	10±4	Cd	321±7	123±5	73±5
Al	17±3	6±3	<16	Sn	112±5	52±8	36±6
S	<44	<38	<40	Sb	444±4	130±10	100±8
Ca	13±10	5±10	8±10	I	1097±39	314±42	101±40
Cr	144±6	36±1	21±1	Ba	<108	<116	<114
Fe	19±2	13±2	9±2	W	422±26	133±35	40±33
Ni	50±1	26±2	19±6	Hg	202±9	108±11	43±12
Cu	32±3	18±2	19±1	Pb	13±3	8±4	<24
Zn	29±2	21±2	18±3	Th	457±4	235±6	202±6
Se	215±11	83±13	58±16	U	572±7	204±5	147±7

$\sim 18\%$ in the energy range ~ 1 Mev (Ref. 8). Such a change in sensitivity affects the value of σ_a to some extent, since in this energy range there is an effect of elastic slowing down of the neutrons in the spheres and, in addition, in the 830-kev energy region there is appreciable inelastic scattering of the neutrons for some of the elements. Reduction of the sensitivity of the counter to elastically and inelastically slowed neutrons acts as an apparent increase in the absorption effect, and consequently raises the value of the absorption cross section.

Attempts were made, both experimentally and by computation, to estimate the increase in σ_a caused by elastic and inelastic neutron collisions. Computation showed that for 830-kev neutrons σ_a may be increased by 24 — 30% because of the variation in counter sensitivity. For 220-kev neutrons, the increase in σ_a varies between 2 and 4%. For 25-kev neutrons the variation in counter sensitivity is so small that it has no effect on the value of σ_a. Separate experiments were carried out with spheres of graphite (which has no appreciable neutron absorption), thick enough to reduce the average neutron energy by a factor of two. The counting rate with the graphite sphere for 25-kev neutrons was hardly changed. For 220- and 830-kev neutrons, the counting rate was lowered by about 3 — 5%.

An analysis of all the errors of the method enables us to estimate the accuracy: for 25- and 220-kev neutrons, the method gives absorption cross sections to an accuracy of 3 — 15%, while for 830-kev neutrons the absorption cross sections are too high by 20 — 30%. In the future we plan experiments with a detector which has a more constant sensitivity in the energy range below 1 Mev (though we pay the price in poorer response at higher energies).

In conclusion, the author expresses his gratitude to O. D. Kazachkovskii for continual help in the work and for valuable advice, and to V. P. Pazovska and I. M. Kopylov who helped in the measurements.

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ELECTRON LOSS AND CAPTURE IN COLLISIONS BETWEEN FAST HYDROGEN ATOMS AND MOLECULES OF GASES

Ia. M. FOGEL', V. A. ANKUDINOV, D. V. PILIPENKO and N. V. TOPOLIA

Physico-Technical Institute, Academy of Sciences, Ukrainian S.S.R.

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The cross sections for capture and loss of electrons in single collisions of 5-kev to 40-kev hydrogen atoms with He, Ne, A, Kr and Xe atoms and with H_2, N_2 and O_2 molecules are measured by a mass-spectrometric method.

INTRODUCTION

THE passage of fast neutral particles through a substance is accompanied by processes of electron capture and loss as the particles collide with atoms of the substance. The first of these processes can occur only if the neutral particle possesses positive electron affinity. As a result of electron capture and loss a neutral beam which has traversed a layer of matter will upon emerging contain singly charged negative ions and positive ions of various charge multiplicities in addition to neutral particles. A beam of hydrogen atoms, each of which can capture or lose only a single electron, will upon emerging include negative hydrogen ions, hydrogen atoms and protons. For thin layers of matter permitting only single collisions the composition of the emerging beam will be determined by the cross sections for electron capture (σ_{0-1}) and loss (σ_{01}) by hydrogen atoms (σ_{ik} is the cross section for a process whereby a particle with charge ie is transformed into a particle with charge ke). For thicker layers, where multiple collisions begin to play a part, the composition of the emerging beam is determined not only by the two cross sections already mentioned but also by σ_{10}, σ_{-10}, σ_{1-1} and σ_{-11}. Of these six cross sections for a hydrogen beam the cross section σ_{10} for the capture of a single elec-