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AECD-4098

(NAA-SR-MEMO-651)

Issue Date:
April 2, 1953

RESONANCE ABSORPTION OF THORIUM

by

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ABSTRACT

Cadmium ratios for very thin (neutron and beta-wise) foils of thorium, gold, vanadium and indium have been measured in the glory hole of the WENS. These cadmium ratios, together with the known thermal cross sections and a given calculated resonance integral for gold, were used to evaluate the resonance integrals of thorium, vanadium and indium. Values obtained were:

<u>Element</u>	<u>Cadmium Ratio</u>	<u>Resonance Integral (barns)</u>
Thorium	1.85	86.4
Vanadium	17.2	1.1
Indium (In ¹¹⁵)	1.75	2,763

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INTRODUCTION

Due to a current interest in the nuclear properties of thorium, recent measurements have been made which allow a re-evaluation of its resonance absorption integral. The value presently in use was obtained by Hughes and Egger¹ in 1946. It was felt that the accuracy of this experiment could be improved by use of slightly different techniques (similar to the method of Ref. 3) and by use of more up-to-date constants in the calculations. In any case a recheck was felt to be worthwhile.

Theory (see Ref. 3)

A measurement of the activation produced in bare foils and cadmium covered foils when irradiated in a neutron flux leads to the cadmium ratio, which is defined as:

$$\text{CdR} = \frac{\text{bare activity}}{\text{cadmium covered activity}}$$

This ratio may be used to compare the fast, or resonance, absorption with the thermal absorption of the material being studied, and may be written as:

$$\text{CdR} = \frac{K \sigma_{\text{tha}} + \sum_a'}{\sum_a'} \quad (1)$$

where K = constant depending on the particular flux of irradiation

σ_{tha} = thermal activation cross section

$\sum_a'$ = effective resonance absorption integral

Solution of equation (1) gives:

$$\sum_a' = \frac{K \sigma_{\text{tha}}}{\text{CdR} - 1} \quad (2)$$

Thus, the effective resonance integral may be obtained from a measurement of the cadmium ratio and a knowledge of the thermal activation cross

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section, provided the constant K is known. K may be found for the particular activation flux by measuring the cadmium ratio for gold, since σ_{tha} is known² for gold and the resonance integral for this element has been evaluated.³

The effective resonance absorption integral, $\sum_a^i$, found in the above manner, is the sum of the absorption due to resonances, $\sum_a$, and that part of the " $1/v$ " absorption which extends beyond the cadmium cut-off:

$$\sum_a^i = \sum_a + \sum_{1/v} \quad (3)$$

The last factor can be obtained from a cadmium ratio measurement for a " $1/v$ " absorber. In this case,

$$\sum_a^i = \sum_{1/v} = K \frac{\sigma_{1/v}}{\text{CdR}_{1/v} - 1} = k \sigma_{1/v} \quad (4)$$

where k depends on the flux. After k is evaluated from equation (4) it may be substituted in equation (3) which can be written in the form:

$$\sum_a^i = \sum_a + k \sigma_{\text{tha}}$$

Where σ_{tha} is the thermal absorption cross section of the material in question. Equation (5) then gives the true resonance integral for a thin absorber with a correction for its " $1/v$ " absorption.

Preparation of Foils

Four types of foils were prepared: gold, indium, vanadium pentoxide, and thorium oxide. The backing material in each case was a one centimeter square, 5 mil piece of high purity bismuth metal. As bismuth is difficult to roll, the bismuth foils were prepared by dripping molten bismuth onto a glass surface. These foils were found to have an activity only a fraction above background after an irradiation of one hour at a flux of 4×10^7 n/cm²/sec.

The gold and indium foils were prepared by vacuum evaporation

to a thickness of about 0.4 mg/cm^2 and 0.04 mg/cm^2 respectively. The thorium oxide foils were made by placing about 0.5 mg of thorium oxide on each bismuth foil, adding a drop of ethyl acetate and spreading the mixture evenly with a small glass rod. The foils were then oven-dried and the resulting thorium oxide layer was found to be stable to careful handling as long as the surface was not touched. These foils were compared before and after cadmium ratio measurements by an irradiation method (which will be discussed later) and in no case was any change in thorium content discovered.

The vanadium pentoxide foils were prepared in a manner similar to that of the thorium oxide foils, except that a drop of solution containing about one part in twenty of polystyrene was used in place of ethyl acetate. The polystyrene bond was necessary in this case, as the vanadium pentoxide did not form a close-packed coat because of the coarser grain and larger quantity (close to 5 mg). The introduction of this small amount of moderator was thought to be permissible, especially since the vanadium measurements were to be used to make a correction in the final results of only about 5%.

In all four types of foils above, the thicknesses were such that the calculated absorption at the resonance peak was no greater than 0.35% (gold). The self-shielding in these foils is, therefore, negligible, since the average flux in a foil is reduced from that outside the foil by an even smaller percent.

Method

The irradiation of the various foils took place in the glory hole of the North American Water Boiler Neutron Source at a flux of about 4×10^7 neutrons/cm²/sec. Two foils of the same material were irradiated in each run, and were held in a 2S aluminum foil holder which had two shelves designated as positions one and two, located two inches on either side of the center of the reactor.

Three different types of foil arrangement were exposed: foil comparison, flux comparison, and cadmium ratio. The foil comparison was accomplished by placing the two foils face-to-face (or, in the case

of thorium oxide and vanadium pentoxide, one over the other, both face up) in position one. The flux comparison was made by placing one foil in position one and one in position two. The cadmium ratio measurement was similar, except that the foil in position two was contained in a ²⁰/₃₀ mil cadmium box. All foils were counted in end window beta counters. The two foils from a given run were counted in each of two counters; then their positions were interchanged and they were counted again. As a rule, over 100,000 counts were obtained from each foil for each position. These counts were corrected for counter resolving time (average) and for counter background and foil background (initial activity of foil). The ratio of activities of the two foils was then obtained as follows: If we define:

- AC_{1A} = Actual count of foil 1 obtained in Counter A
 TC_1 = True count or activity of foil 1 (i.e., the count if counter A were 100% efficient)
 e_A = The efficiency of counter A

Then we may write, for the case of two foils counted in each of two counters, four equations of the type:

$$\begin{aligned}
 AC_{1A} &= (TC_1)(e_A) \\
 AC_{1B} &= (TC_1)(e_B) \\
 AC_{2A} &= (TC_2)(e_A) \\
 AC_{2B} &= (TC_2)(e_B)
 \end{aligned}$$

A simultaneous solution of these equations gives:

$$\frac{TC_1}{TC_2} = \sqrt{\frac{AC_{1A}}{AC_{2B}} \times \frac{AC_{1B}}{AC_{2A}}} = \frac{\text{Activity of foil 1}}{\text{Activity of foil 2}} \quad (5)$$

This equation was used for all runs, the flux and foil comparison results being used as corrections to the cadmium ratios.

Results

The cadmium ratio for ~~vanadium~~ was obtained with the

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intention of using it for the $1/v$ correction given in equations (4) and (5). However, the vanadium measurements give an absorption integral which is considerably larger than that accounted for as $1/v$ absorption by theory (see appendix). For this reason the correction factor obtained experimentally by Harris, et. al, in Ref. 3 (which agrees more closely with theory) was used, and the resulting resonance integral for vanadium is given. A possible explanation of this discrepancy in results is that the WENS flux does not vary as $1/E$ but has a large enough component of fast flux to show up small high energy resonances in vanadium which would not be evident in a more highly thermalized flux. Further experimental work in this subject is intended.

The resonance integrals obtained for vanadium, thorium, and indium are given in the following table. All values are to cadmium cut-off.

Element	Cadmium Ratio	Resonance Integral without $1/v$ correction ($\sum \sigma_a$) (barns)	Resonance Integral with $1/v$ correction ($\sum \sigma_a$) (barns)
Gold	1.76	1,337 ^a	1,296 ^a
Vanadium	17.2	3.1	1.1
Thorium	1.85	89.5	86.4
Indium (In^{115})	1.75	2,850	2,763

^a Calculated

The value of 89.5 barns for the uncorrected thorium resonance integral would have been 87.4 barns if earlier cross section values given by Hughes and Egger¹ had been used. This may be compared, then, with the value of 81.3 barns¹ which they obtained in 1945. The indium value of 2,763 barns is in close agreement with a calculated value of 2,712 barns given in the same reference, and in lesser agreement with an experimental value of 2,294 barns obtained by Harris, Miehllhouse and Thomas (Physical Review 79, No. 1, July 1950).³

Errors

Considering better than 100,000 counts for each of the

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quantities in equation (5) above, the percent probable error due to counting is of the order of 0.5 percent. All runs were repeated with two different sets of foils and were found to be reproducible to less than 1%, except in the case of vanadium which varied about 7%. This latter uncertainty is to be expected as the techniques used are not well-suited to short half-life materials.

From the above considerations the experimental error may be assumed to be in the neighborhood of 1%. However, the quoted² uncertainties in the thermal cross-section, together with an unknown uncertainty in the calculated resonance integral for gold³ would raise the overall uncertainty to, perhaps, 10%.

The constants used are as follows:

Element	σ_{th} (barns)	Reference
Gold	94 ± 1	2
Vanadium	4.7 ± 0.2	2
Thorium	7.0 ± 0.4	2
Indium (In ¹¹⁵)	$197 \left(\begin{smallmatrix} 145 \pm 15 \\ 52 \pm 6 \end{smallmatrix} \right)$	2

$$\begin{aligned} \text{Calculated resonance integral for gold} &= \sum_a = 1,296 \text{ b}^3 \\ \text{Correction factor for } 1/v \text{ absorption} &= k = 0.44 \end{aligned}$$

APPENDIXAbsorption Integral for "1/v" Absorber:

If we define the cross section for a 1/v absorber as,

$$\sigma = \frac{\sigma_{th} V_0}{V} = \sigma_{th} \sqrt{\frac{E_0}{E}}$$

Then the absorption integral becomes,

$$\Sigma_{1/v} = \int_{E_0}^{\infty} \sigma \frac{dE}{E} = \int_{E_0}^{\infty} \sigma_{th} \sqrt{\frac{E_0}{E}} \frac{dE}{E}$$

Integrating,

$$\Sigma_{1/v} = 2 \sigma_{th} \sqrt{\frac{E_0}{E_{ed}}}$$

where $E_0 = 0.025$ e.v., and E_{ed} is of the order of 0.8 e.v. Substituting these numbers,

$$\Sigma_{1/v} = 0.35 \sigma_{th} = k \sigma_{th}$$

The value obtained experimentally by Harris, et.al.,³ was $k = 0.44$. This latter number was used in evaluation of the present data in preference to our experimental value of $k = 0.7$ for vanadium, since it seems more reasonable with regard to the above calculation and also is on a more sound basis experimentally (average of several 1/v absorbers). The theoretical number, 0.35, was not used, as there is some reason to believe that the energy spectrum may be shifted toward the fast side of a 1/E distribution, requiring a larger k for correction. In any case such uncertainties as the flux spectrum and the true absorption of "1/v" absorbers leave the 1/v correction in doubt. It is hoped that the question will be resolved in further work.

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