

Below the cadmium threshold, the neutrons have approximately the Maxwellian distribution as was pointed out above. This is a rather narrow energy range and the chance that a resonance occurs in it is fairly rare. Except for those cases where a resonance below 0.3 ev is known to occur, it is reasonable to suppose that the absorption has a $1/v$ dependence so that the thermal activation is given by:

$$A_{th} = n\bar{v}\sigma(\bar{v}).$$

Here $\bar{v}$ is the average velocity of the C-neutrons, and n is their density. The ratio of the activations is given by:

$$\frac{A_{res}}{A_{th}} = \frac{q}{n\bar{v}} \int_{E_{Cd}}^{\infty} \sigma_a(E) \frac{dE}{E} / \xi \sigma_s \sigma(\bar{v}).$$

The quantity $(q/n\bar{v}) \cdot (1/\xi\sigma_s)$ can be determined from the measurements described above in which a BF₃ counter was exposed to the neutrons from a hole in the pile. These data gave

$$\left(\frac{A_{th}}{A_{res}}\right)(\text{boron}) = 47.1.$$

Since the boron absorption follows the $1/v$ law, we have

$$\sigma(\bar{v}) / \int_{E_{Cd}}^{\infty} \sigma(\bar{v}) \left(\frac{E(\bar{v})}{E}\right)^{\frac{1}{2}} \frac{dE}{E} \left(\frac{E_{Cd}}{2E(\bar{v})}\right)^{\frac{1}{2}}$$

for 0.90 gm/cm³ of Cd we may take $E_{Cd} = 0.4$ ev, while for $E(\bar{v})$ we take 0.042 ev and obtain, thereby, the general expression

$$\frac{A_{res}}{A_{th}} = \frac{0.045}{\sigma(\bar{v})} \int_{E_{Cd}}^{\infty} \sigma(E) \frac{dE}{E}$$

with an uncertainty of about 10 percent resulting from the uncertainty in E_{Cd} . The coefficient 0.045 is in good agreement with the value obtained from an independent method of obtaining this number based on the use of a calibration of indium foils in a "standard graphite pile" which is described elsewhere. This relation is useful in determining the value of $\int \sigma_a(E) dE/E$ from a comparison of the activations induced in a substance with and without cadmium protection.

The work reported here was done in 1943-44. It was carried out under contract between the University of Chicago and the Manhattan District Corps of Engineers, War Department.

Evidence for, and Cross Section of 115 Day Se⁷⁵ *

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Evidence has been given to show that the 115-day activity produced in selenium by thermal neutrons is due to Se⁷⁵ which decays by K electron capture to As⁷⁵, accompanied by a 0.4 Mev γ -ray. A value for the cross section of Se⁷⁴ for radiative capture of a thermal neutron has been given.

SEABORG'S tables¹ report as a K -capture process a 48-day and a 160-day activity for Se⁷⁵ produced from As⁷⁵ by a (p, n) and $(d, 2n)$ reaction, respectively. However, we have found a K -capture activity with a half-life of 115 ± 5 days produced by an (n, γ) reaction on selenium irradiated in the Argonne pile. The remainder of this paper will give evidence for this activity and for a value of the activation cross section for its production from Se⁷⁴.

The 115-day activity was established by counting samples mounted on scotch tape foils with an aluminum-walled cylindrical Geiger counter. One sample was counted for over six months.

Possibility of an arsenic activity produced by an (n, p) reaction on the selenium was ruled out by chemical separations from the selenium using an arsenic carrier. No activity was found in the arsenic fractions. The chemical separation was checked by adding 27-hour As⁷⁶ to non-activated selenium and separating the two elements. No arsenic activity was found in the selenium por-

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¹ G. T. Seaborg, Rev. Mod. Phys. 16, 1 (1944).

TABLE I.

Element	K-absorption edge
Zn	1.2805A
Ga	1.1902A
Ge	1.1164A
As	1.0426A

TABLE II.

Element	$K-\alpha_1$	$K-\alpha_2$
^{34}Se	1.10248A	1.10652A
^{33}As	1.17344A	1.17743A
^{32}Ge	1.25130A	1.25521A

tions. Similar separations with germanium ruled out the possibility of an (n, α) reaction on the selenium to produce germanium. The possibility of the activity being due to impurities in the selenium was ruled out by using a sample of Hilger spectroscopically standardized selenium reported to be 99.9964 percent pure. Samples of selenium of doubtful purity showed this activity to be fully as strong as did the Hilger sample. The only other elements exhibiting half-lives of this order of magnitude, having large cross sections, and which could be impurities (since they have similar chemical properties with selenium), were tellurium and tantalum. Both of these were eliminated by spectroscopic analysis of the Hilger sample.

It then remained to determine the selenium isotope responsible. Since a possible reaction was an (n, γ) reaction on Se^{82} to produce Se^{83} with subsequent beta decay to Br^{83} , which has a 140-minute half-life, a search for a bromine daughter was undertaken. A bromide ion carrier was added to a selenium solution in hydrochloric acid. After allowing 24 hours for the possible bromine daughter to grow, the bromide ion was separated from the selenium ion. No activity was found in the bromine fraction, thus eliminating Se^{83} . The only other possibilities were Se^{75} , Se^{79} , and Se^{81} . The two latter would be negative beta-emitters, whereas the first would be a positron emitter or produce arsenic K x-rays by K -capture. Cloud chamber studies showed that very few beta-particles (positive or negative) were emitted, as will be discussed below. Further evidence for Se^{75} was obtained by bombarding arsenic, which consists of only the one stable isotope As^{75} , with 12 Mev

deuterons from the cyclotron at Washington University in St. Louis. The only possible selenium isotope which could be produced (this by a $(d, 2n)$ reaction) for which no stable isotope was known was Se^{75} . The selenium thus produced was then separated from the arsenic. The decay of the sample also gave a 115 ± 5 day half-life and the mass absorption coefficients for this sample were the same as those for the sample produced by the pile neutrons on selenium.

A study of the radiation emitted showed a γ -ray of about 0.4 Mev, as determined by an absorption curve taken with lead absorbers after electrons and x-rays were absorbed by one centimeter of Lucite. An absorption curve taken on the main radiation with aluminum absorbers gave a mass absorption coefficient of $42 \text{ cm}^2/\text{g}$. This is roughly the value to be expected for x-rays from elements like arsenic or selenium. If K -electron capture were the mode of decay of Se^{75} , arsenic K x-rays would be expected. However, if positron emission were the mode of decay, any x-rays accompanying them would be selenium x-rays. Table I gives the values of the K -critical absorption wave-lengths for several absorbers.² X-rays of wave-lengths slightly shorter than the K -critical values for an absorber are strongly absorbed by it. Table II gives the main K x-ray lines³ for arsenic, selenium, and germanium. We see that if selenium x-rays are present they would be more strongly absorbed by germanium or gallium absorbers than by arsenic absorbers, whereas arsenic x-rays would be more strongly absorbed in gallium or zinc absorbers than in germanium absorbers. If germanium x-rays are present, they would be more strongly absorbed in zinc than in gallium absorbers. Table III gives the values of the mass absorption coefficients for

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Absorber	μ/ρ in cm^2/g
^{13}Al	42
^{30}Zn	115
^{31}Ga	102
^{32}Ge	56
^{33}As	56

² A. H. Compton and S. K. Allison, *X-Rays in Theory and Experiment* (D. Van Nostrand Company, Inc., New York, 1935), second edition, p. 792.

³ Reference 2, p. 784.

various absorbers, as measured by us. Since gallium shows stronger absorption than germanium we must conclude that arsenic x-rays are present due to K -capture in Se^{75} .

In order to verify completely the presence of x-rays and the absence of β -particle decay, a foil of the active selenium was placed in a cloud chamber.⁴ With argon gas in the chamber many short tracks of photoelectrons, having a range about one millimeter and *originating in the gas*, were observed, but few longer electrons (above the background) originated *at the foil*, as is shown in Fig. 1. With helium gas in the chamber, only a few photoelectrons were seen in the gas, and an upper limit on the number of electrons starting from the foil could be fixed. These results showed that only a few percent of the disintegrations could be by positron emission, whereas the major portion is by K -electron capture with subsequent emission of As K x-rays.

The activation cross section⁵ for the production of Se^{75} from Se^{74} by a thermal neutron (n, γ) process was calculated on the basis of the cloud-chamber tracks, on an estimation of the counter efficiency for the arsenic K x-rays, and on an estimation of the counter efficiency for the γ -rays produced. The calculations by the three methods checked fairly well, and a weighted average is $22 \times 10^{-24} \text{ cm}^2/\text{isotopic atom}$, or $0.2 \times 10^{-24} \text{ cm}^2/\text{natural atom}$, since the natural abundance of Se^{74} is 0.9 percent. The probable error is estimated to be about ± 40 percent.

The chemical procedures of separation used were the following. A solution of selenium was prepared by dissolving selenium metal powder in concentrated nitric acid, evaporating to dryness, and redissolving in a minimum of concentrated HCl. Arsenous oxide or germanium oxide carrier was then added and the selenium precipitated by reduction to the metal with sulfur dioxide. The precipitated metal was washed with water, and then with ethyl alcohol, and dried at 110°C . The arsenic or germanium was then precipitated from

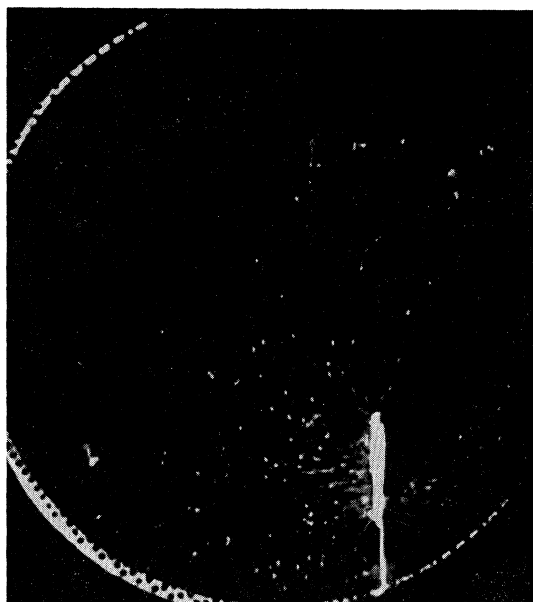


FIG. 1. Cloud-chamber photograph (by D. Hughes and C. Egger) of 115-day Se^{75} . The many small blobs are due to photoelectrons produced in the argon gas from the x-rays. A few beta-rays originating at the foil can also be seen.

the acid solution as a sulfide by use of hydrogen sulfide.

In the case of the cyclotron bombardment, the arsenous oxide was dissolved in concentrated HCl, selenous oxide carrier was added and the selenium was precipitated by reduction with sulfur dioxide.

To look for the possible bromine daughter, selenium was dissolved and the bromine was allowed to grow for 24 hours in the presence of added sodium bromide carrier. Then silver nitrate was added, precipitating silver selenide and bromide which were then redissolved in concentrated aqueous ammonia. The silver bromide was then reprecipitated from hot nitric acid solution in which silver selenide remains soluble.

The mass absorption coefficients were obtained by placing foils of known thickness of the suitable element between the sample and a bell-type, thin mica-window Geiger counter. The absorbers of gallium, germanium, and arsenic were prepared by placing known amounts of the powdered oxides on scotch tape.

⁴ The cloud-chamber work was done by D. Hughes and C. Egger.

⁵ For a fuller discussion of cross-section procedure see a paper on "Thermal neutron activation cross sections," by the same authors (to be published).

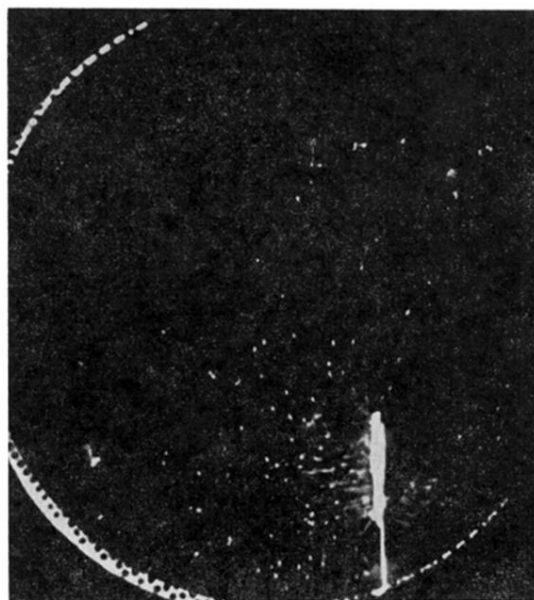


FIG. 1. Cloud-chamber photograph (by D. Hughes and C. Egger) of 115-day Se^{76} . The many small blobs are due to photoelectrons produced in the argon gas from the x-rays. A few beta-rays originating at the foil can also be seen.