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Forty-Three Day $_{48}Cd^{115}$

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A 43-day isotope of cadmium has been discovered while irradiating cadmium with slow neutrons. The radiation consists of β-rays of energy $\sim$1.5 Mev, and with approximately one 0.5-Mev γ-ray per disintegration. By means of chemical separations, the radio element was identified as cadmium, and the mass assignment to $_{48}Cd^{115}$ was made by a fast neutron $In^{115}(n, p)Cd^{115}$ reaction.

1. PREVIOUS INVESTIGATIONS OF 43-DAY CADMIUM

THE radioactive cadmium isotopes have been studied by several investigators in the past,[1] but only Cork and Lawson[2] have mentioned a long period, beta-emitting Cd isotope. They bombarded cadmium with deuterons and from the chemically separated cadmium fraction found a 40-day activity after the short periods had decayed. They suggested that this negative particle emitter was caused by Cd^{115} or Cd^{117} on the basis of other known isotopes.

At the Argonne Laboratory the radioactivity induced in cadmium by pile neutrons was part of a survey of thermal-neutron-induced activities.[3] In addition to the known periods of 3.75 hr and 2.5 days, a very short period of approximately 2 minutes and a long period of 43 ± 3 days were found. The latter two periods have not previously been found with slow neutron irradiation on cadmium.[4] This paper describes the 43-day period and method of isotopic assignment.

II. CHEMICAL IDENTIFICATION OF LONG PERIOD ACTIVITY AS CADMIUM

The cadmium used in this experiment was commercial strip cadmium so that a small amount of indium impurity[5] would give a 48-day activity which could be mistaken for the observed activity in cadmium (see Fig. 1). Furthermore, the 48-day indium might possibly be produced with slow neutrons on cadmium by a chain of activities. Since 3.75-hr. Cd (from slow neutrons on cadmium) produces 117-min. In, and 2.5-day Cd (also from slow neutrons on cadmium) produces 4.1-hr. In, it seemed reasonable that a third activity from slow neutrons on cadmium could give 48-day In.

To test both of these possibilities chemical separations were made. The cadmium metal

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[1] See G. T. Seaborg's "Artificial radioactivity," Rev. Mod. Phys. 16, 1 (1944).

[2] J. M. Cork and J. L. Lawson, *Phys. Rev.* 56, 291 (1939).

[3] Cf. L. Seren, H. N. Freidlander, and S. H. Turkel, *Thermal Neutron Activation Cross Sections*, to be published shortly.

[4] Irradiation in the center of the Argonne graphite pile is not strictly a thermal neutron irradiation, but it is practically so for cadmium, atomic No. 48. The spectrum of neutrons in the pile is predominantly thermal and epithermal resonance neutrons, producing (n, γ) reactions. The fission spectrum of neutron energies does have a high energy tail which may extend to 8 Mev, but such high energy neutrons are quite rare. The samples of this experiment were separated from the uranium lumps by a few inches of graphite which reduces even further the number of fast neutrons. Although fast neutrons can cause (n, p) and (n, α) reactions, the potential barrier is quite high for $_{48}Cd$, making these reactions quite improbable. The $(n, 2n)$ reaction requires very high neutron energies, about 8 Mev, so they, too, are quite improbable. The cross sections for the productions of the observed activities in cadmium are:

Half-life	Isotope	Cross section per natural cadmium atom (cf. footnote 3)
2 min.	Cd?	0.05×10^{-24} cm^2
3.75 hr.	Cd^{117}	0.1×10^{-24} cm^2
2.5 days	Cd^{115}	0.3×10^{-24} cm^2
43 days	Cd^{115}	0.04×10^{-24} cm^2 (may include resonance as well as thermal capture)

These large cross sections leave no doubt that the observed activities were caused by (n, γ) reactions.

[5] The cross section per natural indium atom for the production of 48-day indium with slow neutrons is 2.52×10^{-24} cm^2, cf. footnote 3. Thus 1.5 percent indium in the thin ($\approx$1 mil) irradiated cadmium strips could account for the activity ascribed to cadmium. A spectrographic report received later showed less than 0.01 percent indium present in the cadmium.

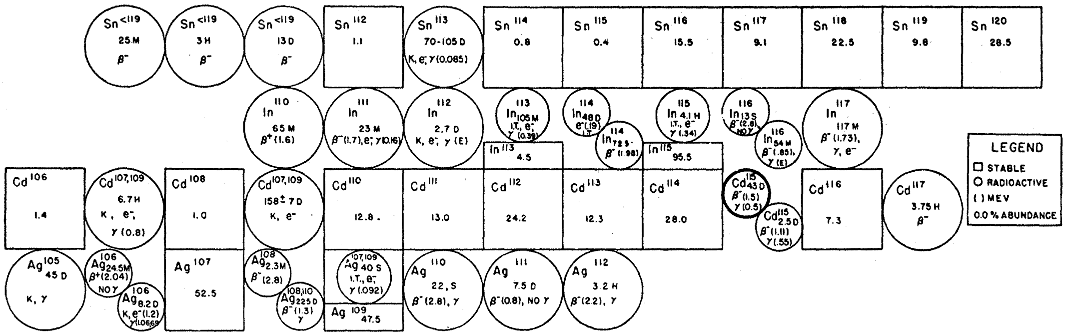

FIG. 1. Partial table of isotopes.

(about two months after irradiation) was dissolved in nitric acid and the indium was then precipitating in an excess of ammonia solution. But the activity remained with the cadmium fraction and did not come down with the indium carrier precipitates. To test the above chemical procedure the following experiments were performed. Cadmium nitrate crystals were irradiated for 10 minutes with pile neutrons and then the indium separated quickly as above. This indium fraction decayed with 2-hr. half-life, hence, it came from the 3.75-hr. cadmium. Next, some more cadmium nitrate crystals were irradiated more strongly and allowed to decay for two days. This indium fraction was then separated and decayed with 4 to 5 hours half-life, hence, it came from 2.5-day cadmium. Thus, the chemical procedure seemed reliable, proving that the 43-day activity was not caused by indium.

There still remained the possibility that the long period activity could be caused by some other impurity in the cadmium metal, such as $_{32}$Te, $_{38}$Sr, $_{51}$Sb, or $_{77}$Ir, which give activities of 32, 55, 60, and 70 days, respectively, when irradiated with slow neutrons. To test this possibility a complete chemical analysis of the cadmium metal was made and the activity remained with the cadmium precipitates and no activity came down with any other precipitates. (This chemical analysis is described at the end of this report.) This proved definitely that the 43-day activity obtained from slow neutrons on cadmium was an isotope of cadmium.

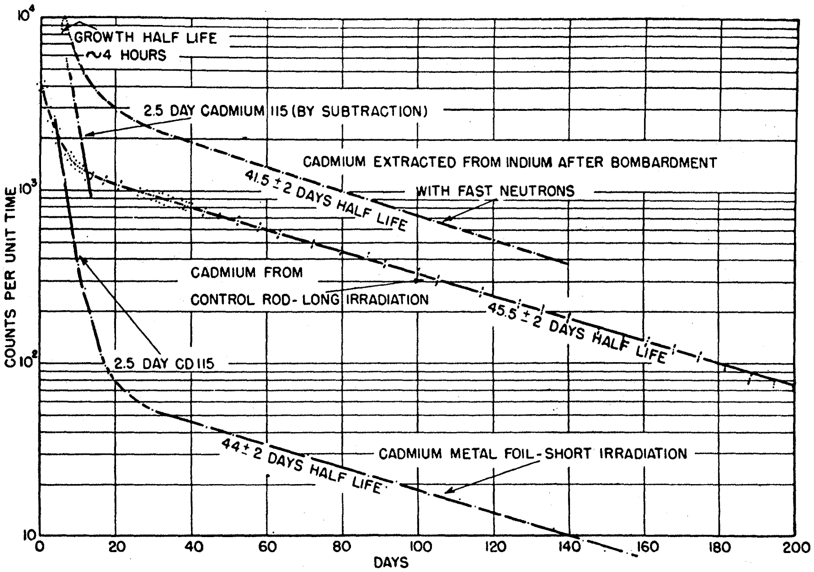

FIG. 2. Cadmium decay curves.

III. HALF-LIFE AND ABSORPTION CURVES

The β-ray activity of three samples[6] of irradiated cadmium metal were followed on a duraluminum Geiger counter for about 150 days, giving half-lives of 44.0±2 days, 41.5±2 days, 45.5±2 days. One of these three samples was followed for 200 days, but tailed off into a longer half-life after 150 days. This is not surprising because no chemical separations were made on these samples of commercial grade cadmium metal. A fourth sample of chemically separated cadmium from indium (bombarded with fast neutrons—see part IV) was followed for 125 days and gave a half-life of 41.5±2 days. These four values give an average value of 43±3 days for the half-life. These decay curves, together with the 2.5 day ${}_{48}Cd^{115}$ activity, are shown in Fig. 2.

Figure 3 shows one of the β-ray absorption curves taken on a cadmium metal foil (70 mg/cm^2 thick). The β-rays seem to have a range of $\approx$640 mg/cm^2 Al, but to this must be added the self-absorption correction of $\approx$40 mg/cm^2 and a counter window plus air correction of 5 mg/cm^2. The total range of 685 mg/cm^2 Al corresponds to a maximum β-ray energy of $\approx$1.5 Mev. This β-ray absorption curve indicates the order of one gamma-ray per beta-particle. Figure 4 shows the absorption of the gamma-rays in Pb which indicates a gamma-ray energy of 0.5 Mev.

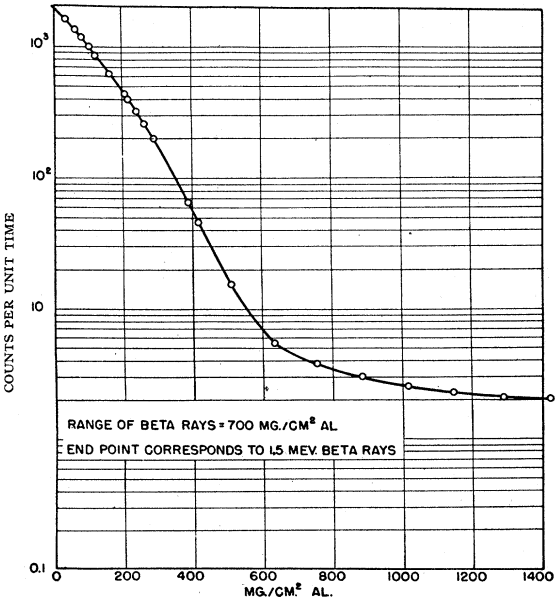

FIG. 3. Absorption of beta-rays from cadmium metal foil showing presence of gamma-rays, 64 days after irradiation with slow neutrons.

IV. MASS ASSIGNMENT OF ${}_{48}Cd^{115}$ BY In(n, p)Cd REACTION

Several grams of indium foil were placed on the target assembly of the St. Louis cyclotron of Washington University.[7] Here the indium foil was bombarded with fast neutrons of maximum energy 16 Mev from deuterons on beryllium. After six days of bombardment, totaling 32,730 micro-ampere hours, the foil was shipped to Chicago and a chemical separation of the cadmium made a few days later. The chemically separated Cd precipitate was followed on a beta-counter and showed a 4-hour growth, then a 2.5-day decay and then a 41.5-day decay (see Fig. 2).

Since the chemically separated Cd precipitate represented the end products of an In(n, p)Cd reaction, the 4-hour growth was interpreted as the In^{115} daughter coming back into equilibrium with its 2.5-day Cd^{115} parent. (See Fig. 1.) Also the 43-day Cd activity was thus limited to either Cd^{113} or Cd^{115} because of the two stable isotopes In^{113} and In^{115}.

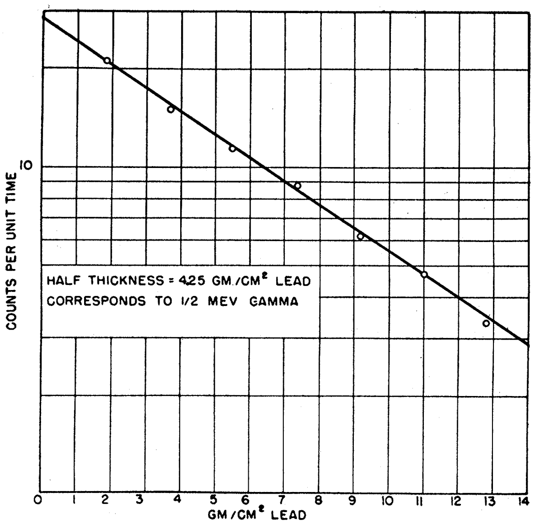

FIG. 4. Absorption of gamma-rays from cadmium metal foil, 64 days after irradiation with slow neutrons.

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[6] One of these samples was prepared from scrapings of the control rod of the pile by Mr. George Miller.

[7] The assistance of Mr. Harry Fulbright is gratefully acknowledged.

The cyclotron bombardment intensity was logged hourly, so that from this data and the ratio of the initial intensities, it was possible to calculate the ratio of the saturated activities of the 2.5-day and 43-day half-lives. This was found to be 1.1 for the cadmium precipitate from indium.

Since indium has only two stable isotopes, In^{113} and In^{115}, and these are rather similar, the cross section for the fast neutron (n, p) reactions for these two isotopes should be of the same order of magnitude. But the natural abundance is 4.5 percent for In^{113} and 95.5 percent for In^{115}. Thus if the 2.5-day and 43-day activity both came from $In^{115}(n, p)Cd^{115}$ the ratio of the saturated activities should be unity. Actually observed ratio was quite close to this, being 1.1. On the other hand, if the 43-day activity came from $In^{113}(n, p)Cd^{113}$, the ratio of 2.5-day to 43-day saturated activities should be $95.5/4.5 = 21$, which is a different order of magnitude from the observed ratio. The 2.5-day Cd activity has been definitely assigned to ${}_{48}Cd^{115}$ by Goldhaber, Hill, and Szilard.[8] Thus it seems reasonable to assign both the 2.5-day and the 43-day activities to isomeric states of ${}_{48}Cd^{115}$.

V. BRANCHING RATIO OF ${}_{48}Cd^{115}$

For two of the cadmium metal samples irradiated with slow neutrons,[9] the ratio of 2.5-day and 43-day saturated activities could be computed as above. The ratios turned out to be 5.5 and 5.2. (The difference can be ascribed to experimental error.) Thus for slow neutron formation of ${}_{48}Cd^{115}$ the branching ratio is about $\frac{5}{6}$ for the 2.5-day activity and only about $\frac{1}{6}$ for the 43-day activity. This indicates that the 43-day activity is somewhat forbidden and is consistent with the fact that the ground state of In^{115} has a high spin of 9/2. Also the 2.5-day activity decays to 4.5-hour In^{115*} which seems to have a small spin.[10]

VI. CHEMICAL ANALYSIS OF CADMIUM

The cadmium metal sample was dissolved in HNO_3 and precipitated in $6N\text{-}H_2SO_4$ with H_2S. The following elements would be precipitated completely—carriers were added: Ag^+, As^{+3}, Au^{+3}, Bi^{+3}, Cu^{+2}, Hg^{+2}, Pd^{+4}, Sb^{+3}, Se^{+4}, Sn^{+4}, Te^{+4}, Pt^{+4}, and Pb^{+2} which would precipitate as $PbSO_4$. The following would precipitate incompletely, and no carriers were added for them, except that As and Te carrier was added in the lower valence state. As^{+5}, Ir^{+4}, Mo^{+6}, Os^{+4}, Re^{+7}, Rh^{+3}, Ru^{+4}, Te^{+6}. The cations Cd^{+2}, Se^{+6}, In^{+3} would not precipitate at all.

From the H_2S precipitate the activity on a standard geometry was 0 ± 5 c/m. The supernatant liquid was then made $\frac{1}{2}N$ in H_2SO_4 and again precipitated with H_2S. This brings down the Cd^{+2}, Se^{+6}, and In^{+3}. The activity on the standard geometry was ≈ 1400 c/m. Next, $In(OH)_3$ was precipitated by NH_4OH and this gave ≈ 4 c/m. One-half of the CdS was then dissolved in HNO_3; the solution was then made alkaline with NH_4OH and H_2S passed through. This precipitate gave ≈ 680 c/m, about half of the original activity which was to be expected if all the activity was from the cadmium. Since Ir and Mo would not be precipitated here they are ruled out, leaving Os, Rh, Re, Ru, and Sr. Of these elements, only two have an activity of the same order half-life as 43 days. Re^{184}, 52-days K-capture activity with 1.5-Mev γ's is formed by an $(n, 2n)$ reaction which was highly unlikely in the pile. Sr^{89}, 55 days, with 1.5 Mev β and no γ is formed by slow neutrons. Sr does not precipitate in H_2S at all, but it would be strongly absorbed on $PbSO_4$, hence, would have precipitated in the first step. But since no activity was observed here, the activity could not come from the Sr, leaving only Cd as the carrier of the activity.

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[8] M. Goldhaber, R. D. Hill, and Leo Szilard, *Phys. Rev.* **55**, 47 (1939). They showed that the 2.5-day cadmium activity could be produced either by fast (Li+D) neutrons or slow neutrons, and that this 2.5-day Cd activity was actually the parent of 4.5-hour ${}_{49}In^{115*}$.

[9] Some of this pile neutron activation may have been caused by epi-thermal neutrons, as mentioned in footnote 4.

[10] Cf. page 48 of footnote 8.