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Radioactive In^{107}, In^{108}, In^{109}, and Sn^{108}

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A new indium isotope which decayed with a 33±2-min. half-life has been produced by deuteron and proton bombardments of cadmium 106. Evidence for the assignment of the activity to indium 107 is given. Characteristic radiations are positrons of 2-Mev energy and gamma-rays. An indium isotope which decayed with a 4.30±0.15-hr. half-life has been produced by a deuteron and proton bombardment of cadmium 108 and by an alpha-bombardment of cadmium 106. The assignment is made to indium 109. Decay is by emission of 0.75±0.05-Mev positrons, by *K*-electron capture, and by emission of gamma-rays. Two genetically related isotopes in tin and indium have been assigned to mass number 108. The tin isotope, which is produced by bombarding cadmium 106 with alpha-particles, decays with a half-life of 4.5 hr. by *K*-electron capture. The indium isotope, which is produced by the decay of the tin isotope and by bombarding cadmium 108 with deuterons, decays with a half-life of about 55 min. by emitting positrons of 2-Mev energy and gamma-rays.

I. INTRODUCTION

SAMPLES of electromagnetically enriched cadmium oxides** were bombarded with 5-Mev protons, 10-Mev deuterons, and 20-Mev alpha-particles. In Table I are given the isotopic abundance supplied with each sample of enriched cadmium and the impurities found by spectroscopic analysis. Included in this table for purposes of comparison are the abundances of natural cadmium.

The samples were prepared for bombardment by pressing the cadmium oxide into slots in chemically pure aluminum target blocks. Resulting activities were measured with a spectrometer counter[1] and with a Wulf unifilar electrometer connected to a calibrated Freon-filled ionization chamber placed below an electromagnet.

Calcium impurity, though not listed in Table I, was found in all enriched cadmium isotopes. Initially this resulted in considerable confusion because calcium bombarded with alpha-particles produced a large yield of scandium 43 which decayed with 3.92-hr. half-life by emission of 1.13-Mev positrons. The most satisfactory method found to remove the scandium from the indium and the tin was to separate the tin by distillation and then to precipitate the scandium from the indium.

TABLE I. Isotopic abundance of enriched cadmium.

	Percent abundance of isotope of mass numbers 106	108	110	111	112	113	114	116	Impurities
Sample enriched in Cd 106	*32.9*	1.5	9.4	7.7	13.5	11.1	19.1	4.7	None
Sample enriched in Cd 108	1.5	*24.8*	33.2	12.0	10.6	4.5	10.3	3.6	0.08% Pb 0.04% Ag 0.04% Cu
Sample enriched in Cd 110	0.1	0.2	*70.0*	18.6	7.0	1.3	2.3	0.5	None
Natural cadmium	1.2	0.9	12.4	12.7	24.1	12.3	28.9	7.6	

After proton bombardments of cadmium oxide, fluorine was removed. If the oxide could be efficiently reduced to the metal prior to the proton bombardment, this would not be necessary. In the reduction of natural cadmium oxide there was too much loss of cadmium by sublimation to jeopardize the small available supply of enriched cadmium oxide.

II. 33-MINUTE INDIUM 107

No previous assignment to indium 107 and no radioactive isotope in indium with a 33-min. half-life has been reported.

When cadmium enriched in isotope 106 was bombarded with deuterons and with protons, there was produced in the indium fraction a new radioactive isotope which decayed with a 33±2-min. half-life by emitting positrons and gamma-rays in excess of the annihilation radiation. The activity was followed for more than seven half-lives. After bombarding cadmium enriched in isotopes 108 or 110 with deuterons and with protons, no such activity was found. Therefore, the activity is attributed to either indium 106 or 107.

The evidence in favor of indium 107 comes from the fact that cadmium 107, which is known to decay with a half-life of 6.7 hr., was found by irradiating cadmium 106 with protons. However, it is conceivable that a very short-lived isotope could be located at indium 107 instead of the isotope which decays with a 33-min. half-life. The mass assignment is thus made to isotope 107 instead of 106.

The positron energy of about 2 Mev was determined with the spectrometer counter.

III. 4.3-HOUR INDIUM 109

It has been reported that the bombardment of silver with alpha-particles produced a radioactive indium isotope which decayed with a half-life of 6.5 hr.[2] The

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** Supplied by the Y-12 plant, Carbide and Carbon Chemicals Corporation, through the Isotope Division, U. S. AEC, Oak Ridge, Tennessee.
[1] L. L. Woodward and D. A. McCown, Rev. Sci. Inst. 19, 823 (1948).
[2] D. J. Tendam and H. L. Bradt, Phys. Rev. 72, 527, 1118 (1947).

assignment of this isotope was to mass number 109. Later a similar experiment indicated a half-life of 5.2 hr.[3]

When cadmium enriched in isotope 106 was bombarded with alpha-particles and cadmium enriched in isotope 108 was bombarded with deuterons and protons, there was produced in the indium fraction a radioactive isotope which decayed with a half-life of 4.30±0.15 hr. by emitting positrons and gamma-rays in excess of the annihilation radiation. The activity was followed for more than six half-lives. The positron- and gamma-activities both decrease with this half-life. The ratio of the ionization produced by the alpha-induced positron- and gamma-activities is about 12 for the ionization chamber used. This ratio for the same activities induced by protons is also about 12. However, for the alpha-induced activities of scandium 43 which decays with a 3.92-hr. half-life, this ratio is about 93.

This indium activity was not found after bombarding cadmium enriched in isotopes 106 or 110 with deuterons and protons, nor after bombarding cadmium enriched in isotopes 108 or 110 with alpha-particles. Therefore, this activity is attributed to either indium 108 or 109. If it is attributed to indium 108, the reaction $Cd^{106}(\alpha,np)In^{108}$ would be required. The similar reaction $Cd^{108}(\alpha,np)In^{110}$ would produce indium 110 which decays with a 1.1-hr. half-life, but this reaction was not detected with the energy used. If this 4.30-hr. activity is attributed to indium 109, the reaction $Cd^{106}(\alpha,p)In^{109}$ would be required. The similar reaction $Cd^{108}(\alpha,p)In^{111}$ was easily observed. Indium 111 decays with 2.84-day half-life. Therefore the isotope which decays with a 4.3-hr. half-life is assigned to indium 109. The expected daughter, silver 109 which decays with a 470-day half-life,[4] was not found as would be surmised from a consideration of the amount of this long-lived x-ray emitter that would be produced.

The x-ray decay curve indicates also a 4.3-hr. half-life. Thus indium 109 decays also by K-electron capture. By the use of the calibrated ionization chamber the ratio of the modes of decay by K-electron capture to positron emission is found to be about 8 to 1.

The energy of the positrons from indium 109 is 0.75±0.05 Mev. The absorption curve and the histograms from which this was determined are shown in Fig. 1.

Indium 109, which decays with a 4.3-hr. half-life is not to be confused with the well-known indium 115 which decays with a half-life of 4.5 hr. The latter is characterized by gamma-emission and by 0.34-Mev internally converted electrons.

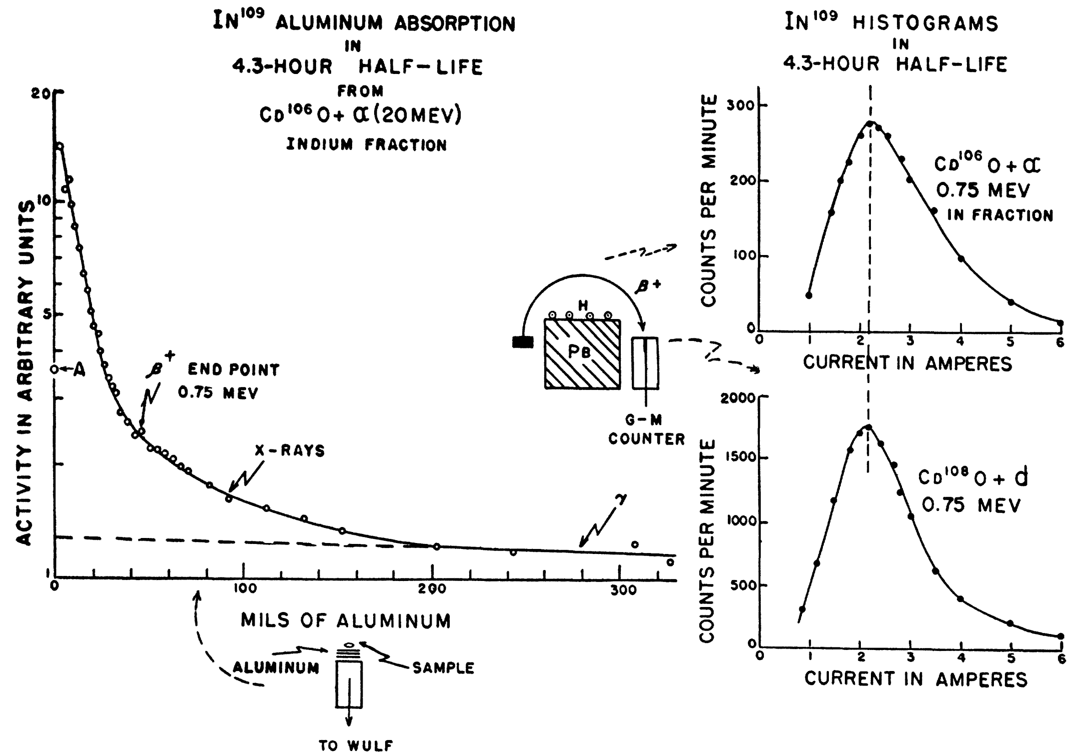

FIG. 1. Aluminum absorption of the alpha-induced activity and histograms of alpha- and deuteron-induced activities in indium 109. The energy of the positrons is shown to be 0.75 Mev. Point A on the ordinate scale of the absorption plot is the intensity of the total electromagnetic radiation from indium 109 for zero absorber thickness.

[3] S. N. Ghoshal, Phys. Rev. 73, 417 (1948).
[4] Gum, Thompson, and Pool, Phys. Rev. 76, 184 (1949).

IV. 55-MINUTE INDIUM 108

An isotope decaying with a 5-hr. half-life has been questionably assigned to indium 108. The reaction postulated is Ag(α,3n).[3]

When cadmium enriched in isotope 110 was bombarded with deuterons, indium 110 was produced. Indium 110 is known to decay with a 1.1-hr. half-life by emitting 1.6-Mev positrons. When cadmium enriched

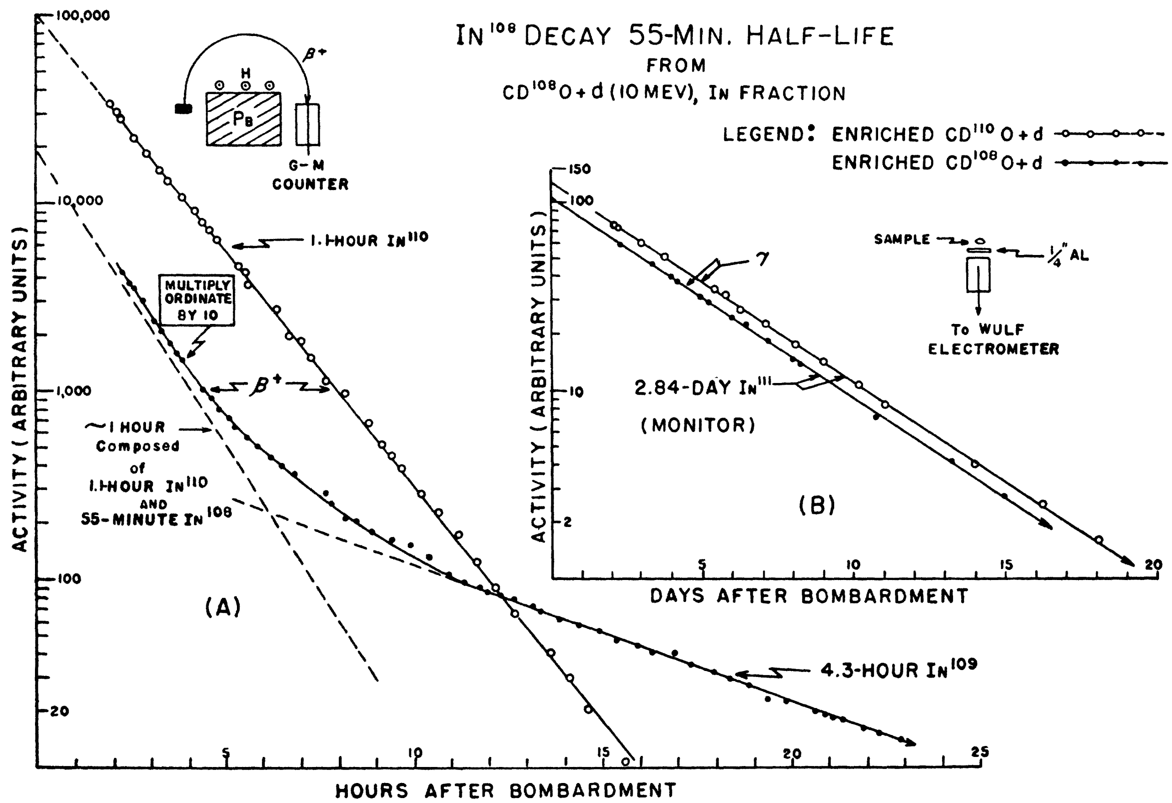

FIG. 2. (A) Comparison of the positron-activity in indium resulting from deuteron bombardments of cadmium enriched in isotope 110, and cadmium enriched in isotope 108. Indium 108 is shown to decay with a half-life less than 1 hr. (B) The comparison was facilitated by monitoring with the gamma-activity of indium 111 produced by the same deuteron bombardments.

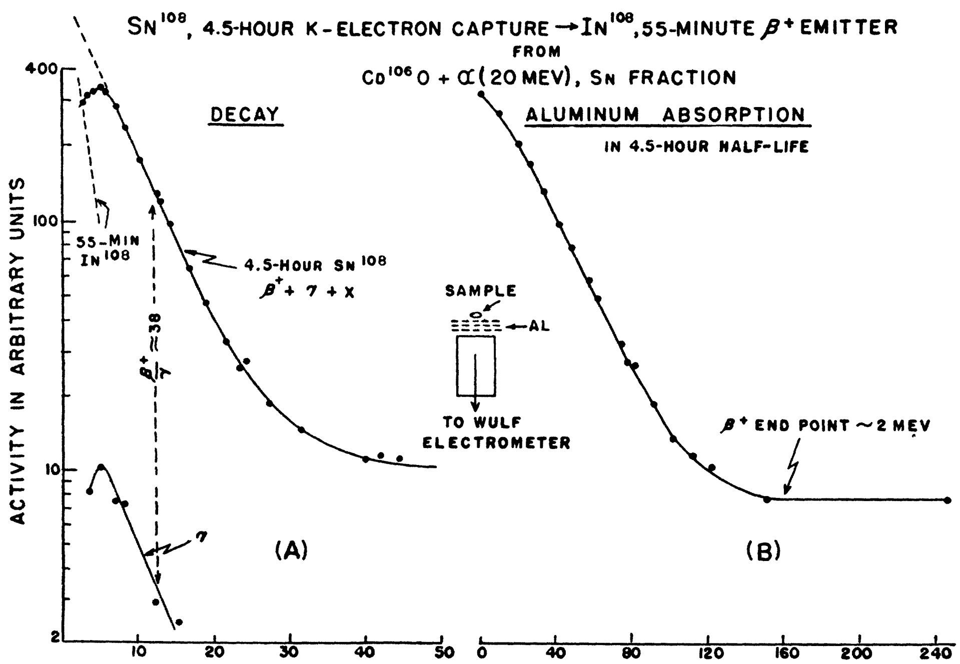

FIG. 3. (A) Build-up of the activities in the tin fraction and the subsequent decay of tin 108 with a 4.5-hr. half-life. The activities were produced by bombarding cadmium enriched in isotope 106 with alpha-particles. (B) Aluminum absorption of the alpha-induced activity in the tin fraction. The absorption which was taken shortly after the activity of the tin fraction reached a maximum, shows that only one positron component was present.

in isotope 108 was given an equal bombardment there was produced in the indium fraction radioactive isotopes which decayed with about a 1-hr. half-life by emitting about 2-Mev positrons. The positron energy was measured with the spectrometer counter. The decay curves for both of these bombardments are shown in Fig. 2(A). Comparison of these positron-activities was facilitated by monitoring with the gamma-radiation from indium 111 which was also produced. Indium 111 decays with a 2.84-day half-life. Figure 2(B) shows the decay curves for indium 111 produced by each of these bombardments. More than twice as much positron-activity resulted from the bombardment of cadmium enriched in isotope 108 than could be attributed to the cadmium 110 present in the cadmium enriched in isotope 108. Therefore, the activity observed must have been composed of the positron-activity of indium 110 which decays with a 1.1-hr. half-life and the positron-activity of another indium isotope which decays with a half-life shorter than the approximate 1-hr. half-life measured. No indium isotope decaying with a comparable half-life is produced by bombarding either cadmium 106 or 110 with deuterons. Therefore, this isotope is either indium 108 or 109.

Cadmium 106 bombarded with alpha-particles does not produce this activity in a measurable quantity. Since the reaction Cd(α,p)In has been observed and the reaction Cd(α,np)In has not been detected with the energy used, the isotope which decays with a half-life less than 1 hr. is assigned to indium 108.

V. 4.5-HOUR TIN 108

No previous assignment to tin 108 has been reported. It has been reported that a tin isotope was produced by a deuteron bombardment of antimony. The tin isotope decayed with 4.5-hr. half-life by K-electron capture to an indium isotope which decayed with a 72-min. half-life by emitting 2.2-Mev positrons.[5]

When cadmium enriched in isotope 106 was bombarded with alpha-particles the intensity of the positron- and gamma-activities of the tin fraction increased initially; the tin fraction then decayed with a 4.5-hr. half-life. Figure 3(A) shows this initial build-up and the subsequent decay of the tin fraction. No such activities were found when cadmium enriched in isotopes 108 or 110 were bombarded with alpha-particles. Therefore this activity results from bombarding cadmium 106 with alpha-particles.

When the activity of the tin fraction reached a maximum, indium was separated chemically. The activity of the remaining tin fraction then increased initially as shown in Fig. 4. The shortest half-life observed in the indium fraction was about 55 min. as also shown in Fig. 4. Positrons were emitted by the indium fraction.

The energy of the positrons emitted by the tin fraction was about 2 Mev. The energy was measured by an

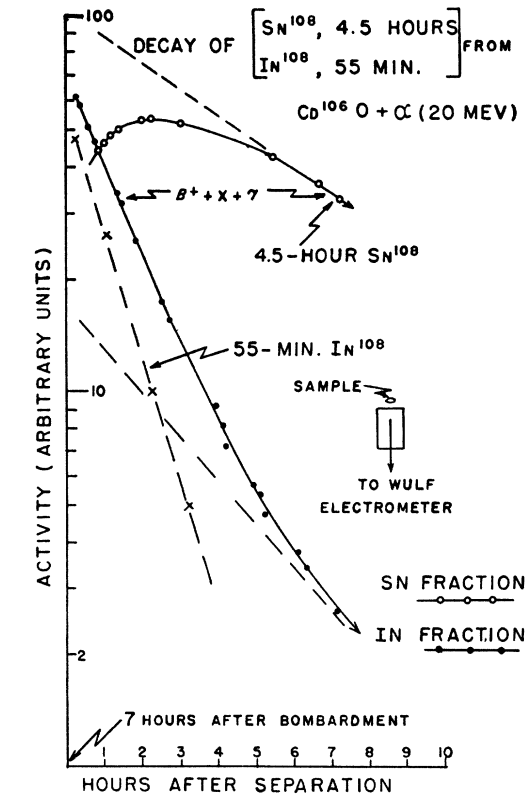

FIG. 4. Decay of indium 108 and the build-up of the activity in the tin from which the indium was removed. Indium 108 was produced by the decay of tin 108. Tin 108 was produced by bombarding cadmium 106 with alpha-particles. Indium 108, which emits positrons, is shown to decay with about a 55-min. half-life.

aluminum absorption taken shortly after the activity reached a maximum. Figure 3(B) shows the absorption curve. Only one positron component was observed in the tin fraction and the indium, formed from the tin, decays by positron emission; therefore, the tin must decay primarily by K-electron capture.

Since this tin isotope was made from an alpha-particle bombardment of cadmium 106, it must be either tin 108 or 109. The daughter isotope in indium must be either indium 108 or 109. However, it has already been shown that indium 109 decays with a half-life of 4.3 hr. and that indium 108 decays with a half-life of less than 1 hr. Therefore, the daughter isotope of the tin fraction is indium 108, and the parent tin isotope is tin 108.

The gamma-activity of the tin fraction increases during the growth of the daughter indium 108. Thus gamma-radiation is associated with the decay of indium 108. The gamma-radiation is in excess of the annihilation radiation.

VI. ACKNOWLEDGMENTS

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[5] G. T. Seaborg and I. Perlman, Rev. Mod. Phys. 20, 613 (1948).