The Natural Radioactivity of In^{115}*

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An investigation of the possible natural radioactivities of the Cd^{113}–In^{113} and In^{115}–Sn^{115} pairs of adjacent isobars gave evidence for a natural beta-radioactivity of indium. Four samples of indium differing in geographical origin were subjected to radiochemical purification and then examined in a screen wall counter arranged with anticoincidence counters and steel shielding. Absorption measurements on these samples gave reproducible results indicative of an energetic natural beta-radiation. The energy was measured by comparing the absorption characteristics of the indium radiation with those of Tl^{204} and Co^{60}, whose beta-energies have been measured spectroscopically. Measurement of isotopically enriched samples of indium gave conclusive evidence that the origin of the beta-radiation is the In^{115} isotope. Limits were placed on possible accompanying gamma-radiation. The results indicate that In^{115} emits a natural beta-radiation of 0.63 ± 0.03-Mev energy with a half-life of $6\pm2\times10^{14}$ years.

I. INTRODUCTION

ACCORDING to the rules of nuclear stability, there should exist no pairs of stable isobars differing by one unit in atomic number. Of the known naturally occurring sets of adjacent isobars the expected activities have been found for the cases of $A^{40}K^{40}Ca^{40}$, $Rb^{87}Sr^{87}$, $Y^{176}Lu^{176}Hf^{176}$, and $Re^{187}Os^{187}$. Of the remaining well-established pairs of neighboring isobars, three have been discussed and investigated:[1–7] $Cd^{113}In^{113}$, $In^{115}Sn^{115}$, and $Sb^{123}Te^{123}$. No results were obtained other than the placing of an upper limit to a possible activity of the isobaric species considered.

Eastman[1] predicted the decay of Sn^{115} to In^{115} on the basis of atomic mass considerations and later[2] collected considerable geochemical evidence which appeared to support the possibility of orbital capture decay of Sn^{115} to In^{115}.

Zingg[3] examined the isotopes In^{113}, Sn^{115}, and Te^{123} for orbital capture by looking for the characteristic x-radiation of the product element in each case. His experiments were carried out by placing samples of each element around a cylindrical Geiger-Müller tube counter with copper walls of a thickness that would give an optimum yield of photo-electrons from the K x-rays expected. The results were negative and indicated a minimum half-life of about 1×10^{12} years for K-capture decay of In^{113}, Sn^{115}, and Te^{123}.

A more sensitive technique for x-ray detection was employed by Rusinov and Igelnitsky[4] in the search for K-capture decay of these same isotopes. They used krypton as the counter gas because of the high mass absorption coefficient of krypton for wave-lengths in the region of the K x-ray energies of Cd^{113}, In^{115}, and Sb^{123}. The samples were placed around the outside of aluminum wall counters arranged with sufficient anticoincidence shielding to reduce backgrounds to about 10 percent of normal. The results were negative and placed the minimum half-life for K-capture of In^{113} at 1×10^{14} years, of Sn^{115} at 1×10^{13} years, and of Te^{123} at 2×10^{14} years.

Kohman[6] plotted the known beta-stable nuclides in such a manner as to indicate the charge of maximum stability for odd mass numbers and drew in a curve representing this quantity following considerations based on the liquid drop model. His results indicate that Sn^{115} should decay to In^{115} and Sb^{123} to Te^{123}, while allowing no conclusions to be drawn about Cd^{113} and In^{113}, which lie nearly equidistant from the stability curve.

Considerable geochemical evidence has been presented against the decay of Sn^{115} to In^{115}. Itsikson and Rusanov[5] have pointed out that tin from pegmatite deposits is usually free of any trace of indium. Ahrens[7] indicated that tin from pegmatitic deposits in southeastern Manitoba, Canada, known to be about 2×10^9 years old, was estimated to occur with 75×10^{-6} percent of indium. This corresponds to a lower limit of 5×10^{12} years for the half-life of possible decay of Sn^{115} to In^{115}.

It would appear in these three pairs of neighboring isobars that either the radiations are too soft or that the rates of decay are too slow for detection by the techniques thus far employed. Bethe and Bacher[8] have shown that very long-lived decay, possibly beyond the limits of detection, could be explained on the basis of forbiddenness considerations. In each of the cases of Cd^{113}–In^{113} and In^{115}–Sn^{115}, a nuclear spin change of four is involved which, when considered with possible parity change, would indicate a third- or fourth-order forbidden transition should be expected. Since the lifetime of a beta-radioactive nucleus increases with decreasing energy of the transition as well as with increasing order of forbiddenness, the possible activities for the two cases cited could easily be unobservable unless considerable energy were available for the transition.

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[2] E. D. Eastman, Phys. Rev. **52**, 1226 (1937).
[3] E. Zingg, Helv. Phys. Acta **13**, 219 (1940).
[4] L. I. Rusinov and J. M. Igelnitsky, C. R. Acad. Sci. U.S.S.R. (Doklady) **49**, 343 (1945).
[5] M. I. Itsikson and A. K. Rusanov, C. R. Acad. Sci. U.S.S.R. **53**, 631 (1946).
[6] T. P. Kohman, Phys. Rev. **73**, 16 (1948).
[7] L. H. Ahrens, Nature **162**, 413 (1948).
[8] H. A. Bethe and R. F. Bacher, Rev. Mod. Phys. **8**, 82 (1936).

In the present investigation the elements tin, indium, and cadmium were examined by more sensitive solid and gas counting techniques, similar to those applied by Naldrett and Libby[9] to the investigation of the Os^{187}–Re^{187} pair of adjacent isobars. Evidence is presented for the natural decay of In^{115} with the emission of an energetic beta-radiation to form Sn^{115}.

II. EXAMINATION OF INDIUM

A. Description of Apparatus

The counting apparatus used for the measurement of solid samples of indium metal and indium hydroxide consisted of a large screen wall counter arranged with anticoincidence shielding counters and steel shielding.

The screen wall counter, described elsewhere,[10–12] introduces the sample directly into the sensitive volume of the counter without an intervening absorber wall by making the sample the counter wall. The counter used consisted essentially of a 3″ diameter brass cylinder 24″ long with a screen-grid counting element suspended concentrically along the middle third of the counter. The sample was placed over 400 cm² area on the inside surface of a 8″ long lead-free brass cylinder. This cylinder was connected by means of a sleeve fitting to an identical cylinder, forming a 16″ unit. Sliding this assembly back and forth inside the counter causes the sample and bare cylinder to be alternately placed in position around the counting element, thus allowing measurement of sample and background counting rates. The counter was operated with the screen-grid grounded and with a negative potential of about 100 volts in the sample cylinder. Application of this "drag-in" voltage makes the effective volume of the counter the entire volume inside the sample cylinder rather than only that inside the screen-grid.

The normal background of the counter described is approximately 450 c.p.m. The employment of a surrounding shield of 8″ to 10″ of hot rolled steel reduced the background rate to about 104 c.p.m. The bulk of this residual count, due principally to the high energy meson component of cosmic radiation, was removed by use of a single completely surrounding layer of counters arranged in anticoincidence. With this combination, samples of 400 cm² area could be measured with backgrounds of about 6 c.p.m.

B. Purification of Indium

Initial measurements on several indium metal samples of high chemical purity gave counting rates of from 50 to 85 c.p.m. above background for 400 cm² sample area and 100 mg/cm² thickness. A rough aluminum absorption curve taken for the lowest activity metal sample indicated that a fairly energetic beta-radiation comprised the bulk of the measured radiation.

Four samples of indium differing widely in geographical origin were submitted to radiochemical purification. The procedure consisted of the dissolution of indium metal in dilute nitric acid, a fluoride precipitation of lanthanum and calcium carriers, a sulfate precipitation of barium carrier, a sulfide precipitation of copper carrier from 0.2N acid solution, and finally the precipitation of indium sulfide from acetic acid solution. After washing, the sulfide was converted to pure indium hydroxide, $In(OH)_3$, in which form it was counted.

This purification procedure is believed to remove or at least highly dilute any of the natural radioactive elements that could be present as contamination in the original sample. A single cycle appeared to be sufficient, since a second purification of one of the samples failed to show any detectable change in the measured activity of the sample and all four samples after purification had identical activities and absorption characteristics within an error of twice the standard deviation for the measurements. These data are presented in Table I and plotted as curve A in Fig. 1.

C. Procedure and Results

After purification the four samples were dried to constant weight in the form of indium hydroxide and ground to a fine powder. A 50-g sample of each was mixed with 50 ml of 0.15 percent agar-water solution and deposited evenly over the 400 cm² area on the inside surface of the sample cylinder. The cylinder was placed inside the screen wall counter and the latter sealed and attached to a vacuum line to dry the sample and evacuate the counter. A filling of 0.5-cm ethylene[13] and 9.5-cm argon was used. Because of the insulating characteristics of indium hydroxide, it was necessary to count the hydroxide samples with a thin aluminum foil over the surface.

Aluminum absorption curves were taken for the four purified indium hydroxide samples and for one metal sample found to be quite free of contamination without

TABLE I. Data on purified natural indium samples.

Sample No.	1	2	3	4	5
Origin	Peru	Montana	Pennsylvania	Heterogeneous	Montana
Chem. form.	$In(OH)_3$	$In(OH)_3$	$In(OH)_3$	$In(OH)_3$	In metal
Al. Abs. (mg/cm²)	(c.p.m.)	(c.p.m.)	(c.p.m.)	(c.p.m.)	(c.p.m.)
0					51.1 ±0.4
2.4	30.4 ±0.4	30.1 ±0.4	31.4 ±0.5	28.6 ±0.4	45.5 ±0.4
4.45	27.9 ±0.5				
6.95					38.7 ±0.5
24.0	11.3 ±0.4				
26.4		9.93±0.40	10.94±0.44	10.74±0.42	16.3 ±0.5
48.0	4.47±0.30				
50.4		4.12±0.32	3.62±0.42	3.33±0.26	6.44±0.45
72.0	1.47±0.41				
85.0					2.22±0.21
87.4		0.42±0.27	1.30±0.36	0.85±0.30	
109	0.59±0.23				1.08±0.22

Sample area = 400 cm²
Sample thickness (minimum) = 120 mg/cm²

[9] S. N. Naldrett and W. F. Libby, Phys. Rev. **73**, 487 (1948).
[10] W. F. Libby, Phys. Rev. **46**, 196 (1934).
[11] W. F. Libby and D. D. Lee, Phys. Rev. **55**, 245 (1939).
[12] E. C. Anderson, Doctoral thesis (University of Chicago, 1949).
[13] Morganstern, Cowan, and Hughes, Phys. Rev. **74**, 499 (1948).

purification. The aluminum foils were placed directly against the sample surface. Because the aluminum foils used evidenced a measurable, though uniform, contamination level, identical foils were mounted over both background and sample side of the sample cylinder for each measurement. It should be noted that an initial high counting rate was frequently observed for freshly prepared indium metal and aluminum foil surfaces. This was undoubtedly the effect described by Crane[14,15] as characteristic of certain metal cathode surfaces, of which aluminum is particularly bad.

The results of these absorption measurements are given in Table I. The absorption data for the hydroxide samples are plotted as curve A, Fig. 1, and that for the metal sample as curve B, Fig. 1. The shape of these absorption curves gives evidence that the radiation consists of a single relatively energetic beta-particle. The extrapolated activity of the hydroxide samples at zero absorber is 34.0±0.4 c.p.m. Correction by the direct mass ratio of indium hydroxide to indium metal gives 49.1±0.5 c.p.m. The extra thickness of the indium hydroxide samples as compared with the metal necessitated a small further correction for a decrease in sample area, raising the hydroxide count to 50.7±0.5 c.p.m., in essential agreement with the 51.1±0.4 c.p.m. activity of the bare metal.

III. ENERGY OF THE INDIUM RADIATION

The energy of the indium radiation was calibrated by comparison of its absorption characteristics with those of two beta-radiations whose energies have been measured spectroscopically. A small amount of Tl^{204}, which emits[16] a 0.77-Mev beta-particle with a half-life of about 3 years, was co-precipitated with 60 grams of indium hydroxide. Absorption measurements were taken as before. The data, corrected for the natural indium activity, are given as curve C in Fig. 1.

TABLE II. Energy and half-life of natural $In^{115}\beta^-$

Isotope used for calibration	$Tl^{204}\beta^-$	$Co^{60}\beta^-$
Energy of radiation	0.77 Mev[a]	0.310 Mev[b]
Range of radiation[c]	284 mg/cm²	80.7 mg/cm²
Absorption half-thickness observed (curves C and D_2, Fig. 1)	20.6 mg/cm²	6.3 mg/cm²
Range $In^{115}\beta^-$ from half-thickness Ratio (H. T. $In^{115}\beta^-$ =16.0 mg/cm²)	220 mg/cm²	205 mg/cm²
Energy[c] $In^{115}\beta^-$	0.64 Mev	0.61 Mev
Half-life $In^{115}\beta^-$	6.2×10^{14} yr.	5.7×10^{14} yr.

Natural $In^{115}\beta^-$

$E(\beta^-)_{max}=0.63\pm0.03$ Mev

$T_{\frac{1}{2}}=(6\pm2)\times10^{14}$ yr.

[a] Reference 16.
[b] Reference 18.
[c] Reference 17.

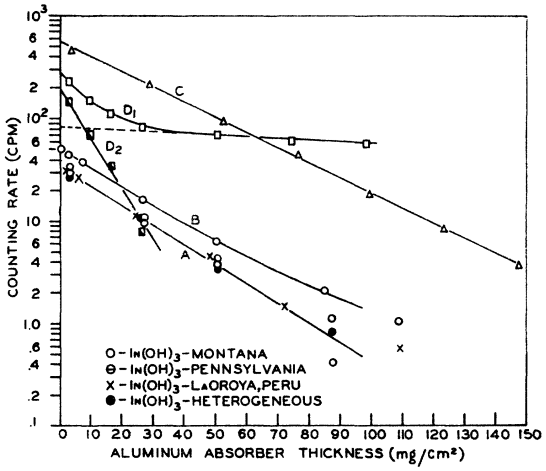

FIG. 1. Absorption curves for natural indium radiation and calibrating Co^{60} and Tl^{204} sources.

It is noted that the absorption curves for both the natural indium activity and the Tl^{204} beta-activity are straight. Therefore, the ratio of the absorption half-thicknesses for the two radiations can be taken as equal to the ratio of their ranges. The range of a 0.77-Mev beta is read from a standard range-energy curve[17] and multiplied by the half-thickness ratio, 16.0/20.6, from curves *A* and *C*. This result, the range of the indium radiation, corresponds to an energy of 0.64 Mev on the standard curve.

In a similar manner a 50-gram sample of indium hydroxide containing a small amount of Co^{60} was prepared and measured. Co^{60} emits a 0.310-Mev beta[18] with a 5.3-year half-life. Curve D_1, Fig. 1, shows the corrected Co^{60} absorption curve including the tail due to gamma-radiation in cascade. Curve D_2, the resolved Co^{60} beta-absorption curve, gives a half-thickness of 6.3 mg/cm² for the cobalt radiation which corresponds to an indium radiation energy of 0.61 Mev. These data are shown in Table II.

Since these two calibrations agree quite well in the resultant energies for the indium radiation, and since the energies of the thallium and cobalt radiations are spectroscopic values, it is believed that the indium radiation has an energy of 0.63±0.03 Mev. This belief, of course, assumes that the shape of the three spectra are similar; but the experimental fact that the absorption curves are linear is perhaps some evidence for this assumption. Moreover, the indium beta is bracketed both in maximum beta-energy and nuclear charge by the Co^{60} and Tl^{204} radiations.

It is of interest to compare this 0.63±0.03 Mev indium beta-energy with that predicted for possible

[14] H. R. Crane, Phys. Rev. **75**, 985 (1949).
[15] M. L. Wiedenbeck and H. R. Crane, Phys. Rev. **75**, 1268 (1949).
[16] Peacock, Jones, and Overman, PPR Mon N-432, 56 (December, 1947), unpublished.
[17] L. E. Glendenin, Nucleonics **2**, No. 1, 25 (1948).
[18] L. C. Miller and L. F. Curtiss, J. Research Nat. Bur. Stand. **38**, 359 (1947).

beta-radiation of In^{115} by the work of Bell *et al.*[19] They found that the 4.4-hour isomeric state of In^{115} gave beta-radiation presumably to Sn^{115} of about 830-kev energy. Since the isomeric state is known to lie 338 kev above the ground state of In^{115}, one might expect that the energy of natural beta-decay of In^{115} to Sn^{115} would be equal to the difference of these two numbers, or 490 kev. It is quite possible either that the discrepancy may be the result of experimental error in the determination of the energies of the beta-radiations or that the beta-transition from the 4.4-hour metastable state of In^{115} may decay to an excited state of Sn^{115}.

IV. HALF-LIFE OF THE NATURAL INDIUM RADIATION

The absolute counting efficiency of the screen wall counter relative to the energetic indium beta-radiation can be estimated from the absorption half-thickness and the energy of the indium radiation which have been experimentally determined above. The mass absorption coefficient, α (in cm^2/mg), is determined from curve A, Fig. 1 to be 0.0436 cm^2/mg.

If a radioactive sample of surface area A and specific activity σ is counted with a physical geometry, g, the measured intensity for a thin element, dl, parallel to the surface is given by,

$$dI = A\sigma g e^{-\alpha l} dl. \quad (1)$$

Then the total measured activity for a sample of thickness l becomes,

$$I = A\sigma g(1-e^{-\alpha l})/\alpha. \quad (2)$$

The intensity for an indium sample of thickness equal to the range l_0 (215 mg/cm^2) is,

$$I_\infty = A\sigma g l_0/9.4. \quad (3)$$

Since g for the screen wall counter used is a little less than 0.5, it appears that the absolute counting efficiency, $g/9.4$, is a little less than 5.3 percent.

In connection with researches on natural radiocarbon[20] the absolute efficiency of the screen wall counter was determined to be 5.46±0.03 percent for a carbon sample of 400 cm^2 area and infinitely thick (20 mg/cm^2) with respect to the 0.15-Mev C^{14} beta-radiation. It appears from the agreement between the estimated efficiency for the indium radiation and the experimental value for C^{14} that the value of 5.46 percent for carbon can be assumed to hold for indium. It is improbable that such an assumption would introduce an error of more than 20 percent in the indium half-life.

It has been shown above that an indium metal sample of 400 cm^2 area and of thickness large with respect to the range of the natural indium radiation gave a counting rate of 51.1±0.4 c.p.m. Using 5.46 percent as the absolute counting efficiency for a sample of thickness equal to the range (215 mg/cm^2), the specific activity σ for indium, by Eq. (3) above, is found to be 10.9 disintegrations per minute per gram. This corresponds to a half-life of $6\pm2\times10^{14}$ years for a beta-radiation from In^{115}. Conclusive evidence that the origin of the indium beta-radiation is the In^{115} will be given in a following section.

TABLE III. Evidence against natural gamma-emission.

Sample	Potassium chloride	Indium metal
Weight	425 g	750 g
Gamma-activity	141.0±2 c.p.m.	0.8±0.6 c.p.m.
Maximum yield for 1.5-Mev γ's		1 per 100 betas
Maximum yield for 0.5-Mev γ's		5 per 100 betas
Maximum yield for 0.1-Mev γ's		84 per 100 betas
Minimum half-life of In^{113} for positron emission		2×10^{15} years

V. EVIDENCE AGAINST NATURAL GAMMA-EMISSION

Because both of the indium isotopes are isobaric with neighboring elements, the beta-radiation from indium could be attributed either to the decay of In^{115} to Sn^{115} with emission of negative betas or to the less probable positron decay of In^{113} to Cd^{113}. A test for the latter possibility was made by looking for the annihilation gamma-radiation that would accompany position decay.

A cylindrical sample of indium metal weighing 750 grams was placed around the outside of a large brass-walled Geiger counter of 670 mg/cm^2 wall thickness. This arrangement, counted with anti-coincidence shielding, yielded an effect of 0.8±0.6 c.p.m. above background. A 425-gram sample of potassium chloride was identically placed and similarly counted with a resultant effect of 141±2 c.p.m. above background. Each of the samples covered a cylindrical area of about 60 square inches around the center half of the counter.

Assuming the energy of the potassium gamma to be 1.5 Mev and taking the half-life of K^{40} as 1.4×10^9 years with a branching ratio of 1:15 for the K-capture decay with which the gamma-radiation appears to be in cascade, the absolute counting efficiency of the brass-walled counter used is determined to be 0.64 percent for 1.5-Mev gammas. Applying this efficiency factor to the measured effect of 0.8±0.6 c.p.m. for the 750-gram indium metal sample, a maximum yield of 1 gamma per 100 betas is obtained. Using the gamma-efficiency data for brass-walled counters given by Maier-Liebnitz[21] and making the necessary self-absorption and wall absorption corrections for the lower gamma-energies, the remainder of the results shown in Table III were calculated. Since the measured rate of natural indium beta-radiation would correspond to a half-life of about 2×10^{13} years, one would expect to get 100 times as many 0.5-Mev gammas from the annihilation of such positions as were obtained in this experiment. Thus the evidence conclusively establishes that no appreciable part of the measured natural indium activity can be attributed to position decay of In^{113}.

[19] Bell, Ketelle, and Cassidy, Phys. Rev. **76**, 574 (1949).
[20] Libby, Anderson, and Arnold, private communication.
[21] von H. Maier-Liebnitz, Zeits. f. Naturforsch. **1**, No. 5 (1946).

The ratios shown in Table III indicate that maximum energy of gamma-radiation that could be in cascade with the 0.63-Mev beta-radiation of indium is certainly less than 0.5 Mev and would appear to be about 100 kev. In all likelihood there is no accompanying gamma-radiation.

VI. ENRICHED SAMPLE MEASUREMENT

To prove the identity of the beta-emitting isotope, two samples of isotopically enriched indium were obtained from the Isotopes Development Division, Oak Ridge, Tennessee. One sample of 400 mg of indium oxide, In_2O_3, was enriched fifteen-fold in In^{113} and the other sample of 22.83 gm of indium oxide was 99.92 percent In^{115}, indicating fifty-threefold dilution of In^{113}.

The enriched In^{113} sample was deposited on a 400 cm^2 area brass foil by evaporation from indium chloride solution and counted. A sample of unenriched indium of similar size was measured for purposes of comparison. The enriched In^{115} sample was counted as indium hydroxide. The results of these measurements appear in Table IV together with predicted values for each sample calculated by Eqs. (2) and (3) above. The initial result for the enriched In^{115} sample indicated radioactive contamination. After purification by the chemical procedure outlined earlier, the enriched In^{115} sample activity showed agreement with the activity expected for natural beta-decay of In^{115}. Purification was not attempted in the case of the smaller sample enriched in In^{113} because of danger of loss and also because the result was quite conclusive despite the contamination. From the data of Table IV it is quite clear that it is indeed In^{115} which is the origin of hard beta-radiation measured in this research.

VII. RESULTS

It has been shown that the In^{115} isotope in its natural state exhibits decay to Sn^{115} by radiation of a beta-particle of 0.63 ± 0.03 Mev energy with a half-life of $6\pm2\times10^{14}$ years. The corresponding specific activity is 11 disintegrations per minute per gram of indium. It was further shown that the maximum energy of accompanying gamma-radiation consistent in a 1:1 ratio with the beta-disintegration rate is of the order of 100 kev. Thus, it appears that the ground state of In^{115} lies between 600 and 760 kev above that of Sn^{115}.

In view of the high energy and long corresponding half-life of the In^{115} radiation, it is of interest to consider the order of forbiddenness of this beta-transition. The spins of these isobars are known, that for In^{115} being 9/2 and that for Sn^{115} being $\frac{1}{2}$. In addition, the orbital assignments[22] are "g" for the ground state of In^{115} and "s" for Sn^{115}, corresponding to no parity change. For a spin change of four and even parity the Gamow-Teller selection rule indicates a fourth-order forbidden transition. The energy and half-life of the In^{115} beta-radiation corresponds to an Ft value of 2×10^{22}. This value is of the order of 10^5 larger than values for known third-order forbidden transitions, lending further support to the argument that the transition from In^{115} to Sn^{115} is fourth forbidden.

[22] M. G. Mayer, Phys. Rev. **75**, 1969 (1949).

TABLE IV. Data on enriched indium samples.

Sample	Natural indium	Enriched in In^{113}	Enriched in In^{115}
Abundance in In^{115}	95.77%	34.6%	99.92%
Abundance in In^{113}	4.23%	65.4%	0.08%
Chemical form	$InCl_3$	$InCl_3$	$In(OH)_3$
$In(OH)_3$ equiv.	0.40 gms	0.48 gms	24.5 gms
Expected rate if activ. is $In^{113}\beta^+$	1.53 c.p.m.	29.0 c.p.m.	0.60 c.p.m.
Expected rate if activ. is $In^{115}\beta^-$	1.53 c.p.m.	0.66	33.0 c.p.m.
Experimental rate without purification	—	2.44 ± 0.5 c.p.m.	44.1 ± 0.5 c.p.m.
Experimental rate after purification	1.64 ± 0.24 c.p.m.	—	33.2 ± 0.4 c.p.m.

Results for the $Cd^{113}-In^{113}$ Pair

In this research several facts relative to the activity limits for each member of the Cd^{113}–In^{113} pair were obtained.

The investigation of possible gamma-radiation from indium indicated that the minimum half-life of In^{113} relative to emission of 0.5-Mev gamma-radiation is 1×10^{15} years, corresponding to a minimum half-life for positron emission of 2×10^{15} years.

The measurement of the enriched In^{113} sample indicated a maximum effect of 2 c.p.m. attributable to the combined effects of contamination, backscattering, and Auger electrons resulting from possible K-orbital capture decay of In^{113}. When it is assumed that 2 c.p.m. are caused by K Augers of about 25-kev energy with 25 percent yield, the corresponding minimum half-life for K-capture decay of In^{113} is determined to be 2×10^{13} years. The investigation of enriched In^{113} as indium trimethyl in large gas counters using proportional counting techniques should provide at least two orders of magnitude greater sensitivity for detection of soft Auger electrons from possible orbital capture activity of In^{113}.

A spectroscopically pure sample of cadmium metal was measured in the screen wall counter with anti-coincidence shielding. This sample, of 500 mg/cm^2 minimum thickness over 400 cm^2 area, gave a net activity of 1.32 ± 0.24 c.p.m. The effect could be at-

TABLE V. Summary of results for Cd^{113}–In^{113}.

Minimum $T_{\frac{1}{2}}$ of In^{113} for 0.5 Mev γ's	1×10^{15} years
Minimum $T_{\frac{1}{2}}$ of In^{113} for β^+ emission	2×10^{15} years
Minimum $T_{\frac{1}{2}}$ of In^{113} for K-capture	2×10^{13} years
Minimum $T_{\frac{1}{2}}$ of Cd^{113} for β^- emission of energy ≤200 kev	$\sim10^{11}[E\ (\text{kev})]^{5/3}$ years
(a) For 20 kev β^-'s	1×10^{13} years
(b) For 200 kev β^-'s	6×10^{14} years

tributed to contamination or to the transition effect. Assuming a 1.5 c.p.m. maximum beta-activity for 400 cm² of cadmium metal counted at 5.46 percent efficiency, the variation of minimum half-life with maximum beta-energy can be determined. Effective sample thickness is taken as the range from standard range-energy curves for beta-radiation. Results for betas up to 200 kev are shown in Table V.

Through the kindness of Dr. J. V. Dunworth, researches conducted in 1947 and described in a Ph.D. thesis by S. G. Cohen on the possible orbital capture activity of In^{113} have recently been made available to us. Their data appear to exhibit evidence of the same activity of natural indium which we have investigated. The authors are indebted to the Isotopes Division of the Oak Ridge National Laboratory for the remarkable isotopically enriched indium samples made available to them.

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Proton Groups from the Deuteron Bombardment of Boron*

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Protons emitted when boron enriched to 96 percent B^{10} was bombarded by 3.76-Mev deuterons have been observed at 90° and 0°. Groups corresponding to Q-values of 9.18±0.05, 7.03±0.06, 4.70±0.06, 4.15±0.08, 2.26±0.07, 1.36±0.07, 0.70±0.10, and 0.32±0.10 Mev were found. These have relative intensities at 90° of 1, 0.3, 0.8, 0.6, 16, 13, and 0.8. The intensity of the lowest energy group was not determined, since it was only just distinguishable from the scattered beam. The bombardment of unseparated boron gave no significant results, because of the presence of large amounts of an impurity, probably magnesium as the boride.

I. INTRODUCTION

IT is well known that the study of the particle groups emitted by an element under bombardment gives information concerning the energy levels in the residual nucleus. The reaction $B^{10}(d,p)B^{11}$ is of more than usual interest because of the large energy release, or Q-value, which enables very highly excited levels in the B^{11} nucleus to be observed.

This reaction was first studied by Cockcroft and Walton,[1] and then more carefully by Cockcroft and Lewis,[2] using 550-kev deuterons and unseparated boron isotopes. They observed three proton groups, corresponding to Q-values of 9.14±0.06, 7.00±0.05, and 4.71±0.03 Mev, as corrected by Livingston and Bethe,[3] which they assigned to the $B^{10}(d,p)B^{11}$ reaction. A few years later, a fourth group was found by Pollard, Davidson, and Schultz,[4] having a Q-value of 2.39±0.20 Mev, using 3.1-Mev deuterons from a cyclotron, and again, unseparated isotopes. Although they assigned this group also to the reaction involving B^{10}, its large yield made it seem likely that it was due to $B^{11}(d,p)B^{12}$. Since their resolution was not very good, it was felt that it would be profitable to repeat their work using the separated isotopes now available from Oak Ridge, and the much better resolution possible with our present counting techniques.

II. PROCEDURE

Boron targets having a thickness of about 3 mm of air-equivalent, or 50 kev at our beam energy, were prepared by evaporating the element off a wolfram filament onto a thin (0.04 mil) gold backing in a vacuum of 10^{-5} mm of mercury. It was necessary to replace the filament several times during the evaporation, since the boron reacted with the wolfram to form the rather brittle

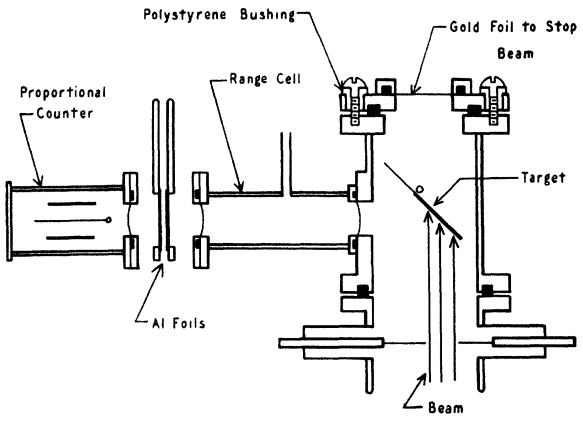

FIG. 1. Schematic diagram of bombardment chamber used. The beam analyzing magnet and slit system have been omitted.

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‡ Assisted by the ONR and AEC.
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