Decay of In^{110m}†

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The K–L conversion electron energy differences of two transitions with energies equal to 0.1131 and 0.1200 Mev were determined in a permanent magnet spectrograph. These experimental differences (0.02265 Mev) are in agreement only with the K–L_I energy difference of cadmium. Therefore neither of these transitions can follow an isomeric transition in In^{110m}. Energy measurements of two other transitions (0.4614 and 0.5840 Mev) combined with the 0.1200-Mev transition energy measurement show that the 0.1200- and 0.4614-Mev transitions are not in cascade, in parallel with the 0.5840-Mev transition, as proposed by Yoshizawa.

INTRODUCTION

THE decay modes of 66-min In^{110}, 4.9-hr In^{110m}, 24-sec Ag^{110}, and 253-day Ag^{110m} to the levels of Cd^{110} as summarized in the *Nuclear Data Sheets*, are shown in Fig. 1. The additional levels proposed by Yoshizawa[1] are shown at the right side of the figure. The spin of In^{110m} has been directly determined[2] to be 7. The spin and parity (2+) of In^{110} have been inferred from the observations that this level decays by positron emission and electron capture to the 1.474-Mev (2+) level, but not to the (0+) ground state, or the 1.541-Mev (4+) levels of Cd^{110}. Therefore the isomeric transition in In^{110}, if it did occur, would have to be an $E5$ or an $M5$. Such a transition would have a K/L ratio <1 (see Fig. 2). McGinnis[3] and Bleuler *et al.*,[4] before the In^{110m} spin measurement, observed a 0.120-Mev transition with a K/L ratio of 4.5 in the decay of In^{110m} and it was suggested that this might be the isomeric transition. This possibility can now be ruled out on the basis of the K/L ratio. In^{110m} has recently been studied by Kato *et al.*[5] and they have proposed that the 0.120-Mev transition occurs in Cd^{110}. It is

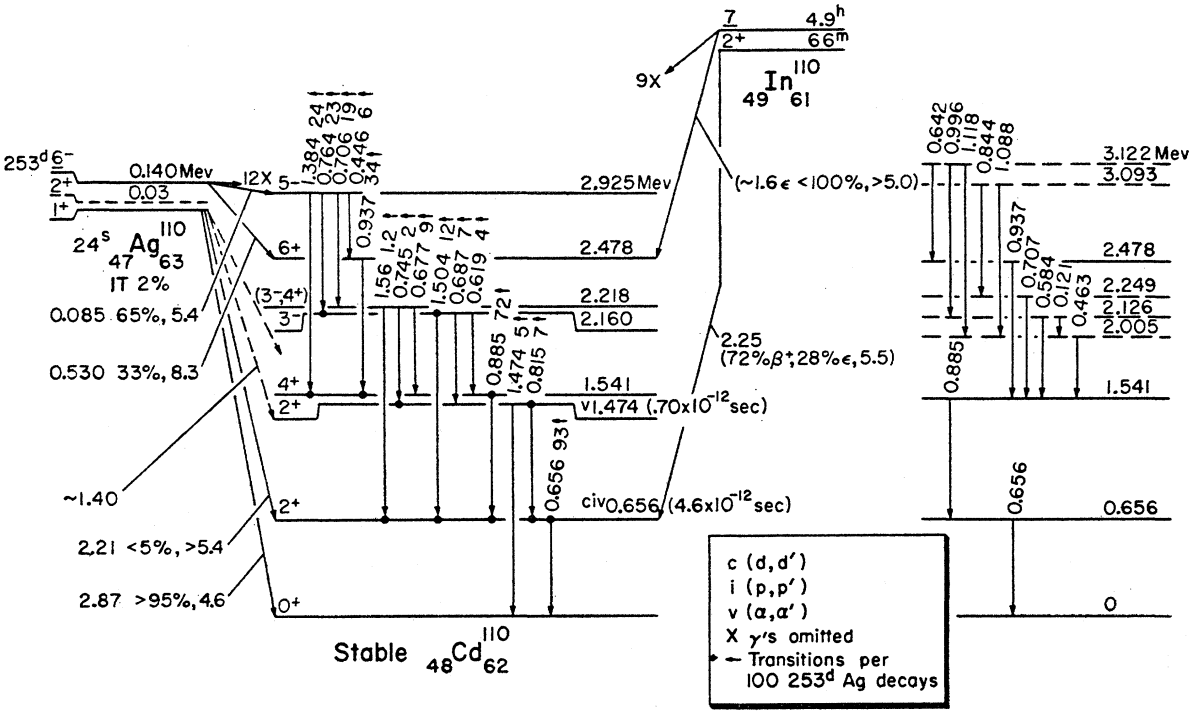

FIG. 1. The decay modes of In^{110}, In^{110m}, Ag^{110}, and Ag^{110m} to levels of Cd^{110}; as summarized in the *Nuclear Data Sheets*. The additional levels proposed by Yoshizawa[1] are shown at the right side of the figure.

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[1] Y. Yoshizawa, private communication reported in *Nuclear Data Sheets*, National Academy of Sciences National Research Council (U. S. Government Printing Office, Washington, D. C.).

[2] L. L. Marino, W. B. Ewbank, W. A. Nierenberg, H. A. Shugart, and H. B. Silsbee, Phys. Rev. **111**, 286 (1958).

[3] C. L. McGinnis, Phys. Rev. **81**, 734 (1951).

[4] E. Bleuler, J. W. Blue, S. A. Chowdary, A. C. Johnson, and D. J. Tendam, Phys. Rev. **90**, 464 (1953).

[5] T. Kato, M. Nozawa, and Y. Yoshizawa, Phys. Soc. Japan, Annual Meeting (October, 1959), reported in *Nuclear Data Sheets*.

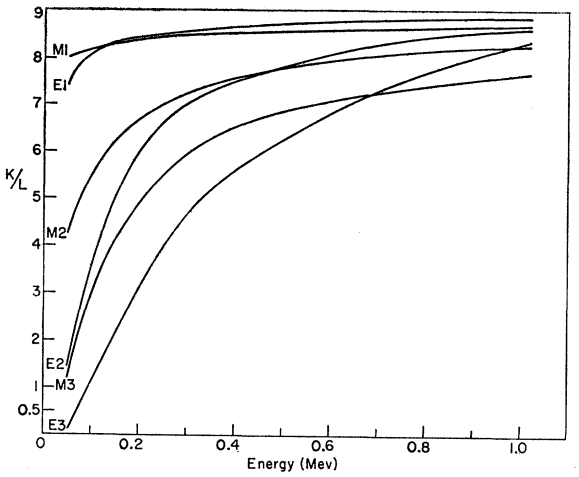

FIG. 2. Theoretical K/L ratios for $Z=48$ (see Rose[13]).

evident the latter is not the In^{110} isomeric transition, but it still could occur in In^{110} following the isomeric transition.

The principal aim of the present work was to measure accurately enough the energy difference of the K and L conversion electrons of the 0.120-Mev transition to determine whether this transition is converted in indium or in cadmium.

EXPERIMENTAL PROCEDURE AND RESULTS

The In^{110m} used in the present study was produced by bombarding natural silver metal with ~19-Mev helium ions in the Purdue cyclotron. In^{110}, In^{111}, and In^{112} were also produced in the bombardment. The target was allowed to cool off ~1 hr before the chemical separation was started. The chemical separation technique of Jacobi[6] was used. The top layer of the bombarded silver was removed by filing. The silver was dissolved in a few drops of 1:1 HNO_3, and 1 mg each of Mg^{++} and Cd^{++} carriers were added and diluted to 5 ml with H_2O. NH_3 gas was bubbled into the solution at boiling temperature to precipitate $Mg(OH)_2$ which carried the indium. Both silver and cadmium form complex ions with the NH_3 and remain in solution. The $Mg(OH)_2$ was washed with a NH_4OH-$(NH_4)_2SO_4$ solution and then dissolved in 1.4M H_2SO_4. The $Mg(OH)_2$ precipitation and washings were repeated. The $Mg(OH)_2$, containing the indium activities, was dissolved in an electroplating solution which consisted of 12 mg of ammonium formate per ml with the pH adjusted to 3.0 with 1.4M H_2SO_4. The indium was electroplated over a 1-cm length on the front (the side toward the spectrograph) of a 0.010 in.-diam platinum wire, in a cell shown in Fig. 3.

This plating procedure has the following advantages. The resolution of the spectrograph is improved since none of the electrons are emitted from the back of the source wire with subsequent loss of energy in passing through part of the wire. The recording film has less background due to exposure by some of the unconverted gamma rays from the nonuseful activity on the back of the wire. Finally, if the amount of source material is limited it is advantageous to deposit it only on the front side of the wire.

The cell body was machined of Lucite. A vertical slit was cut in the cell with a saw of 0.013-in. width. The depth of the slit was sufficient that when the spectrograph source holder was resting on the top of the cell, the source wire was ~$\frac{1}{8}$ in. above the bottom of the slit. A hole for the second electrode was drilled through the cell. A 0.010-inch-diam platinum wire was sealed with Duco cement in this hole. The side of the source mounting wire nearest the source holder was covered with fingernail polish. The cell was filled with the active solution above the source wire to within ~$\frac{1}{8}$ in. of the top of the cell. In spite of the fact that the cell contained a 0.013-in.-wide slit which was partially below the solution level, almost none of the solution was lost through the slit in the entire procedure. The bubbles produced by the electrolysis of the water stirred the solution sufficiently to give a good plating yield in a relatively short time. After plating from a weak acid solution the fingernail polish was loosened to the extent that it could be easily removed in one piece. A final advantage of this source preparation technique is derived from being able to position the mounting wire accurately in the holder before any activity is deposited on it. This is quite desirable when the final sources have an intensity of the order of roentgens per hour at a distance of a few centimeters.

It should be noted that the above chemical procedure is not extremely specific. However, there was no visible deposit on the source wire after the electroplating, indicating that the separation from silver was quite good. Also no conversion electrons from Cd^{107}, which would be produced by a $(d,2n)$ reaction on Ag^{107} by deuteron impurities in the cyclotron beam, were observed. Sources of sufficient intensity to follow the decay of the conversion electron lines could not be

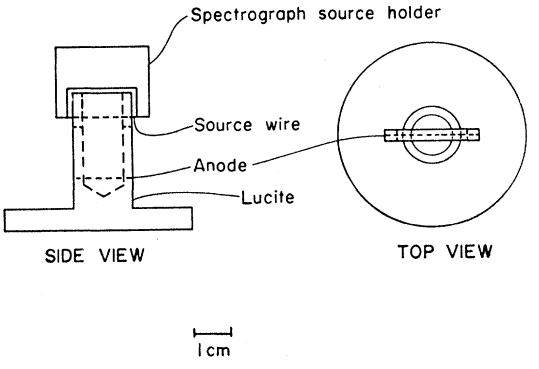

FIG. 3. Electrodeposition cell.

[6] E. Jacobi, Helv. Phys. Acta 22, 66 (1949).

TABLE I. In^{110m} and In^{111} conversion electron energy determinations obtained with low-field spectrograph.

Film number	Electron energy (Mev)	Assignment	K-L energy difference (Mev)
31	0.09324	0.1200-K	0.02265
	0.11589	0.1200-L_I	
	0.14430	0.1711-K	0.02263
	0.16693	0.1711-L_I	
57	0.08642	0.1131-K	0.02261
	0.10890	0.1131-L_I	
	0.09324	0.1200-K	0.02248
	0.11585	0.1200-L_I	
	0.14430	0.1711-K	0.02265
	0.16695	0.1711-L_I	
60	0.08645	0.1131-K	0.02273
	0.10928	0.1131-L_I	
	0.09332	0.1200-K	0.02283
	0.11605	0.1200-L_I	
	0.14456	0.1711-K	0.02256
	0.16712	0.1711-L_I	

produced. It was shown, however, that all of the electron lines decayed with a shorter half-life (or -lives) than that of In^{111} (2.8 days) and the more intense lines were observed to have a much shorter half-life (or -lives) than In^{111}.

The decay of In^{109} has been studied by Petroff.[7] The most intense conversion electrons are the K electrons of a 0.205-Mev transition. This transition was not observed in the present work; therefore the weak lines reported here cannot be assigned to In^{109}.

A period of 4–5 hr elapsed from the end of bombardment until the exposure was begun; therefore the contribution of the 66-min In^{110} would be quite small.

The conversion electrons were studied in two permanent magnet spectrographs with fields of 90 and 225 gauss. The two spectrographs are designated PM I and PM II, respectively. Electrons with energies up to 0.935 Mev could be recorded in PM II. The relative energy errors are estimated to be 0.05%; the absolute energy errors are estimated to be 0.15%. The relative intensities were measured with a photodensitometer and chart recorder. The intensity errors are estimated to be 15% for the strong lines and 25% for the weak lines.

In addition to the 0.120-Mev transition, a second low energy (0.1131 Mev) transition with sufficient intensity to determine the K–L conversion electron energy difference was observed. The K conversion electrons of the latter transition had been previously observed by Dupke.[8]

The K–L energy difference of the 0.1711-Mev transition in the decay of In^{111} was determined as a check on this procedure for assignment of the element in which transitions occur. These measurements were made with PM I. The results of the energy measurements are given in Table I.

The relative intensities of the K and L conversion electrons of the 0.1711- and 0.2452-Mev transitions in In^{111} decay were measured to evaluate the present intensity determinations of the In^{110} conversion electrons.

The average energies of the above transitions and the results of the measurements with PM II, including intensities where measureable, are given in Table II. The intensities are normalized to a 0.6572-Mev K-electron intensity of 100. The results of McGinnis[3] and Bleuler *et al.*[4] are also shown in Table II. The energies shown were obtained in the present work.

DISCUSSION

The K–L_i conversion electron energy differences for silver, cadmium, and indium are given in Table III. The electron binding energies were taken from the compilation of Hill *et al.*[9]

The experimental low-energy K–L electron-energy differences for In^{110m} and In^{111} are given in Table I.

The 0.1711-Mev transition[10,11] in In^{111} decay is 98% $M1$ and 2% $E2$; therefore internal conversion in the L_I subshell predominates. The three experimental values obtained for the K–L difference of this transition, 0.02263, 0.02265, and 0.02256 Mev, are in excellent agreement with the difference obtained using the K and L_I cadmium electron binding energies, 0.02269 Mev.

The experimental K–L differences obtained for the 0.1200-Mev transition in In^{110m} decay, 0.02263, 0.02248, and 0.02283 Mev, are in good agreement with the K–L_I cadmium electron energy difference, 0.02269 Mev.

The experimental values obtained for the 0.1131-Mev transition in In^{110m} decay, 0.02261 and 0.02273 Mev, are also in good agreement with the K–L_I cadmium energy difference, 0.02269 Mev.

The conclusions from these two measurements are that both the 0.1200- and 0.1131-Mev transitions are internally converted in cadmium and, therefore, neither can follow an isomeric transition in In^{110m}. Also, the experimental energy differences indicate that both transitions are largely converted in the L_I subshell.

The ratio of the intensities of the 0.1711-K to 0.2452-K conversion electrons was presently determined to be 1.75 ± 0.25. This is in agreement with the average of the three previous measurements (1.86) (see *Nuclear Data Sheets*). The K/L ratios of the 0.1711- and 0.2452-Mev transitions were found to be

[7] M. D. Petroff, thesis, University of California Radiation Laboratory Report UCRL-3538, 1956 (unpublished).
[8] C. F. Dupke, Jr., thesis, Purdue University, August, 1957 (unpublished).
[9] R. D. Hill, E. L. Church, and J. W. Mihelich, Rev. Sci. Instr. **23**, 523 (1952).
[10] F. Gimmi, E. Heer, and P. Scherrer, Helv. Phys. Acta **29**, 147 (1956).
[11] R. M. Steffen, Phys. Rev. **103**, 116 (1956).

TABLE II. In^{110m} and In^{111} conversion electron measurements made with both spectrographs. The intensity measurements of McGinnis[3] and Bleuler *et al.*[4] are also shown.

Transition energy (Mev)	Electron intensities			McGinnis[3] intensities		Bleuler *et al.*[4] intensities	
	K	L	K/L	K	L	K	L
0.1131	20	W					
0.1200	110	18	6	82	18	160	35
0.1711[a]	170	23	$7\frac{1}{2}$				
0.1871	W[b]						
0.2452[a]	[100][c]	22	$4\frac{1}{2}$				
0.2772	?[d]						
0.3902	?						
0.4614	8						
0.5841	9						
0.6408	40						
0.6572	[100]	16	$6\frac{1}{2}$	[100]		[100]	
0.6767	W						
0.7063	35						
0.8832	45			13		42	
0.9360	30			13		27	

[a] In^{111}.
[b] W = weak.
[c] [ ] = normalized.
[d] ? = presence questionable.

7.5 ± 1 and 4.5 ± 1, respectively. The averages of five previous measurements,[12] are 7.5 and 5.5 respectively.

The K/L ratio of the 0.1200-Mev transition was presently found to be 6 ± 1. McGinnis[3] and Bleuler *et al.*[4] determined the K/LM ratio for this transition to be 4.5 ± 1. The L/M ratio is ~2.5, fairly independent of transition multipolarity.[13] This factor would make the two latter K/L ratios 6.5 ± 1. Kato *et al.*[5] determined this ratio to be 6.1. All of these measurements are in good agreement.

Kato *et al.*,[5] on the basis of their K/L ratio (6.1) for the 0.1200-Mev transition, proposed that this transition is an $E2$ or $M3$. From Fig. 3 it can be seen that a K/L ratio of 6 would require a 40% $M1$–60% $E2$ mixture or an $M2$ transition. The $M3$ assignment proposed by Kato *et al.*[5] has a theoretical value of 3.5 which is not in agreement with the experimental results. The 40% $M1$–60% $E2$ mixture would give an L_{III} conversion electron intensity equal to $\frac{1}{2}$ of the L_I intensity.[13] It was noted earlier that the 0.1200-Mev transition appears to be largely converted in the L_I subshell. Therefore, the $M2$ ($L_I \gg L_{II}$ and L_{III}) assignment is presently preferred.

Yoshizawa[1] has placed the 0.1200-Mev and 0.463-Mev transitions in cascade, in parallel with a 0.584-Mev transition. Using the presently determined relative energies for these transitions, 0.1200 ± 0.0001, 0.4614 ± 0.0002, and 0.5840 ± 0.0003 Mev, respectively, it can be seen that the energy sum of the 0.1200- and 0.4614-Mev transitions does not equal, within the experimental errors, the energy of the 0.5840-Mev transition. Hence it appears that this portion of Yoshizawa's scheme is incorrect.

Most transitions in medium-weight nuclei have $M1$ and/or $E2$ multipolarities. In the present case the 0.1200-Mev transition is interpreted as an $M2$; this requires a parity change and at least one level in Cd^{110} with negative parity. Therefore the discussion of transition probabilities and level populations should await further data on the gamma-ray intensities.

CONCLUSIONS

Two transitions with energies of 0.1131 and 0.1200 Mev and sufficient intensities to permit K–L conversion electron energy difference measurements were observed in In^{110m} decay. The experimental results show that

TABLE III. K–L_i electron binding energy differences (in Mev) for silver, cadmium, and indium.

	Silver	Cadmium	Indium
K–L_I	0.02554−0.00383=0.02171	0.02671−0.00402=0.02269	0.02793−0.00423=0.02370
K–L_{II}	0.02554−0.00355=0.02199	0.02671−0.00373=0.02298	0.02793−0.00393=0.02400
K–L_{III}	0.02554−0.00338=0.02216	0.02671−0.00354=0.02317	0.02793−0.00373=0.02420

[12] D. Strominger, J. M. Hollander, and G. T. Seaborg, Revs. Modern Phys. **30**, 585 (1958).
[13] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).

both of these gamma rays are converted in cadmium. Therefore neither can follow an isomeric transition in In^{110m}.

The present energy measurements of the 0.1200-, 0.4614-, and 0.5840-Mev transitions indicate that the two former transitions are not in cascade, in parallel with the latter, as proposed by Yoshizawa.[1]

ACKNOWLEDGMENTS

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Decay of Neodymium-147

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The decay of Nd^{147} has been investigated using scintillation spectroscopy and coincidence technique. The following sequences of gamma emission have been uniquely established: 91-kev gamma ray is in coincidence with 120, 199, 277, 322, 400, 442, and 599-kev gamma rays; 120-kev gamma ray with 322- and 413-kev gamma rays; 199-kev gamma ray with 400- and 491-kev gamma rays; 277-kev gamma ray with 322- and 413-kev gamma rays; and 310-kev gamma ray with 322- and 413-kev gamma rays. On the basis of these gamma-gamma sequences, the levels of Pm^{147} at 91, 413, 491, 533, 690, and 723 kev above the ground state are unambiguously established. A critical analysis of the observed coincidence spectra shows that the levels at 182 and 230 kev, suggested by other workers, either do not exist or, if they exist, are not populated by any beta transition of intensity more than a percent or by any gamma transition from other higher energy levels, of intensity more than 0.1%.

INTRODUCTION

THE decay of 11-day neodymium-147 has been repeatedly studied by various workers.[1–10] It has been investigated by various techniques but a unique decay scheme is not yet established.[10] The levels of Pm^{147} at 91, 413, 533, and 690 kev, suggested by Hans *et al.*[2] on the basis of gamma-gamma coincidence measurements, have been confirmed. The level scheme is shown in Fig. 1. An additional gamma-ray cascade of 199- and 400-kev gamma rays, introduced by Cork[5] *et al.* between the 91- and 690-kev levels, is also confirmed by later workers.[9] But the order of emission of 199- and 400-kev gamma rays and consequently the location of an additional level at 290 or 491 kev remained uncertain. A second additional level at 230 kev was suggested by Evans[6] to accommodate the gamma rays of energy 230, 260, and 300 kev which were originally reported by Rutledge *et al.*[1] Recently the beta spectrum of this activity has been investigated by Wendt *et al.*[10] On the basis of the analysis of the beta spectrum they suggest a level at ~182 kev being populated by a beta transition of intensity about ten percent and decaying mainly by a 91-91 kev gamma-ray cascade to the ground state; thus they postulate two 92-kev gamma rays. In view of this prevailing situation it was

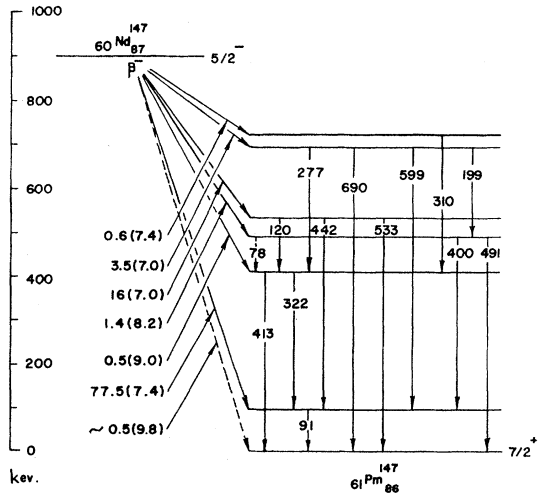

FIG. 1. Decay scheme of Nd^{147}. The intensities of the beta groups are followed by the log*ft* values given in parentheses.

[1] W. C. Rutledge, J. M. Cork, and S. B. Burson, Phys. Rev. **86**, 775 (1952).
[2] H. S. Hans, B. Saraf, and C. E. Mandeville, Phys. Rev. **97**, 1267 (1955).
[3] G. T. Ewan, M. A. Clark, and J. W. Knowles, Atomic Energy of Canada Limited PR-P-30, 1956 (unpublished).
[4] T. Lindquist and L. Karlsson, Arkiv Fysik **12**, 519 (1957).
[5] J. M. Cork, M. K. Brice, R. G. Helmer, and R. M. Woods, Phys. Rev. **110**, 526 (1958).
[6] P. R. Evans, Phil. Mag. **3**, 1061 (1958).
[7] A. C. G. Mitchell, C. B. Creager, and C. W. Kocher, Phys. Rev. **111**, 1343 (1958).
[8] D. Berenye, Nuclear Phys. **8**, 607 (1958).
[9] E. Bodenstedt, H. J. Körner, F. Friesius, D. Hovestadt, and E. Gerdau, Z. Physik **160**, (1), 33 (1960).
[10] Hans-Dietrich Wendt and Peter Kleinheinz, Nuclear Phys. **20**, 169 (1960).