Decay of 66-Min $_{49}In^{110}$†

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A source of pure 66-min In^{110}, particularly free from 4.9-h In^{110m}, has been made by bombarding a natural indium foil with about 100-MeV protons, and chemically separating tin (predominantly Sn^{110}, which is the parent of only 66-min In^{110}) from the indium target. Scintillation spectrometer studies have shown that the well known 280-keV gamma ray is emitted in the decay of 4-h Sn^{110} to 66-min In^{110}, and the following gamma rays are emitted in the decay of 66-min In^{110}: 656, 820, 1120, 1400, 1630, 1780, 2130, 2300, 2400, 2600, 2750, 3000, 3400, and 3650 KeV. The following levels in Cd^{110}, fed from the decay of 66-min In^{110}, are postulated: 656, 1474, 1541, 1790, 1910, 2060, 2820, 3110, 3400, and 3650 keV. From the study of gamma rays in simultaneous coincidence with two annihilation quanta, the intensity of the positron branching to the 656-, 1474-, and 1790-keV states are estimated to be 71, 0.2, and 0.1%, respectively. The logft to these states are calculated to be 5.5, 7.4, and 7, respectively. It is concluded that the allowed positron decay to the 1474-keV state is retarded by a factor of about 100.

I. INTRODUCTION

THE radiations from the decay of 66-min In^{110} have recently[1] been studied with the source produced by Ag(α,xn) reaction. The source had the contamination of 4.9-h In^{110m} and of 21-min In^{112m}. It was reported that in this decay, the levels of Cd^{110} at 656, 1474, 1810, 2160, and 2200 keV are excited. The maximum energy of positrons emitted in this decay is 2.2 MeV and they feed the 656-keV state. It was estimated that the logft values of the decay to the 656- and 1474-keV states are 5.8 and 6.1, respectively.

It is possible to make 66-min In^{110} by another method, which can give a much purer source than is obtained by the alpha-particle bombardment on silver. By making Sn^{110} (half-life 4 h, spin and parity 0^+) whose decay produces only the 66-min In^{110} (2^+) and not the 4.9-h In^{110m} (6), one can get a really pure source. From the extensive studies of Ag^{110m} (6) (Ref. 2) and In^{110m} (6),[2] the high spin states of Cd^{110} are known. The decay of 24-sec Ag^{110} (1^+) is poorly known[2] and is rather hard to study because of the short half-life. Sn^{110}, in the circumstance, provides a very good source to investigate the low spin states of Cd^{110} and to study the positron branching to the excited vibrational states.

II. SOURCE PREPARATION

The 4-h Sn^{110} was produced by the bombardment of a natural indium foil with about 100-MeV protons. After waiting for about 4 h, by which time, Sn^{111} (35-min), Sn^{109} (18-min), and Sn^{108} (9-min) had decayed away, tin was separated from indium by the Cupferon method.[3] This tin sample was Sn^{110} with a trace of Sn^{113}. In^{110} grew in this sample with a half-life of about 60 min.

III. SCINTILLATION SPECTROMETER STUDIES

The gamma rays from a source of Sn^{110}, a few minutes after separation from the indium target, were studied with a 3-in.×3-in. NaI(Tl) crystal detector unit and a 400-channel pulse-height analyzer. The spectrum is reproduced in Fig. 1A. The spectrum from the same source taken 2 h later is given in Fig. 1B, where one can see the decay of the 280-keV gamma ray, and the growth of 511-keV annihilation radiation, 656-, 820-, 900-, and 1120-keV gamma rays. When In^{110} had reached

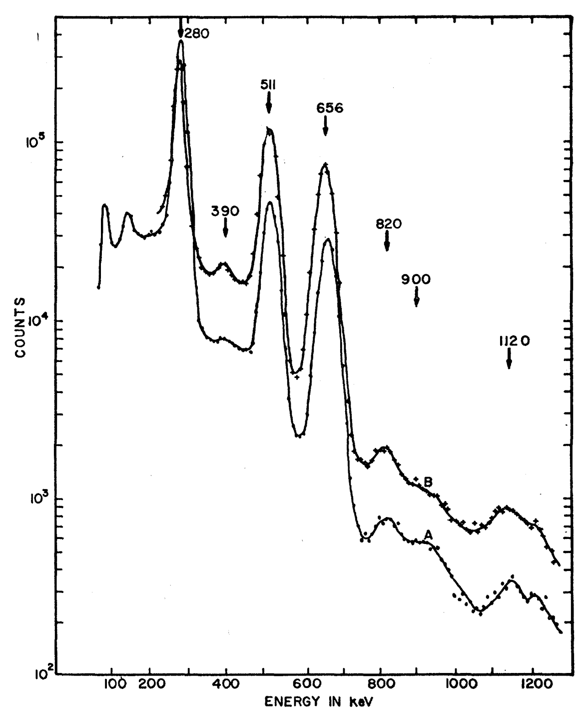

FIG. 1. A: Gamma-ray spectrum of Sn^{110}. B: Gamma-ray spectrum of Sn^{110} taken 2 h later showing the growth of In^{110}.

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* Summer visitor.
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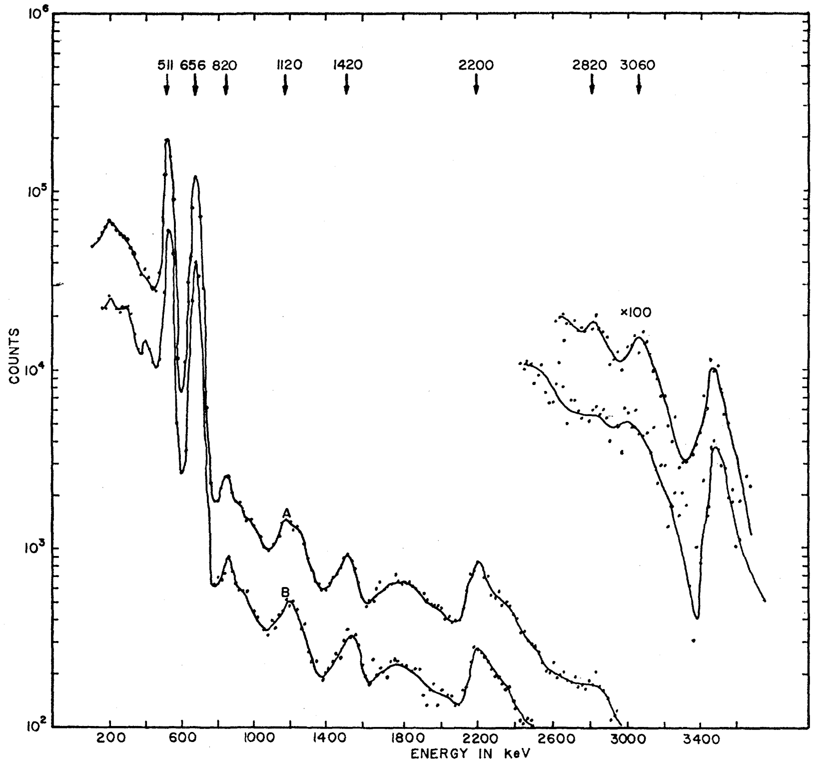

FIG. 2. A: Gamma-ray spectrum of In^{110}. B: Gamma-ray spectrum of In^{110} taken 2 h later showing the decay.

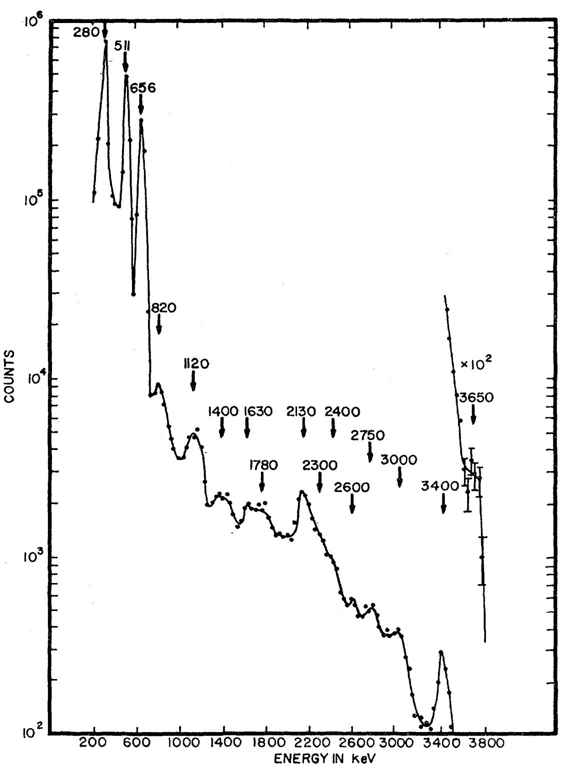

FIG. 3. Spectrum of gamma rays of Sn^{110}–In^{110}.

equilibrium with Sn^{110}, pure In^{110} was extracted. The spectrum of gamma rays from this pure source of In^{110} is reproduced in Fig. 2A, and the one taken 2 h later is given in Fig. 2B. The smallness of the intensity of the 280-keV gamma ray is a measure of the purity of the source. The way the gamma rays grow and decay indicates that the annihilation radiation and the higher energy gamma rays all come from the decay of In^{110}. The gamma-ray spectrum from a strong source of Sn^{110}–In^{110}, placed at a distance of about 15 cm from the detector is given in Fig. 3, where one can see peaks of gamma rays having the energy of 280 keV, 511-keV annihilation radiation, 656, 820, 1120, 1420, 1630, 1780, 2130, 2300, 2400, 2600, 2750, 3000, 3400, and 3650 keV. If one examines the expanded spectrum in Fig. 2, it is clear that the gamma-ray peaks in the energy region 820–3000 keV are complex.

IV. COINCIDENCE STUDIES

Coincidence studies of the gamma rays were made with two 3-in.×3-in. NaI(Tl) crystal units and a 400-channel pulse-height analyzer. The coincidence unit had a resolving time of 50 nsec. The gamma-ray spectrum with the 656-keV gamma ray in the gate is shown in Fig. 4, where one can see peaks corresponding to the gamma rays of energy of 820, 1120, 1250, 1400, 2160, 2450, and 2800 keV. The peak at 656 keV may be due to the inclusion in the gate of the Compton pulses of the higher energy gamma rays. There may be gamma

TABLE I. Energy of gamma rays in keV.

Gamma rays observed in scintillation spectrometer (Figs. 1, 2, 3)	280	390	511	656	820	900	1120	1250	1420		1630	1780	2130	2300	2400	2600	2750	3000	3400	3650
Gamma rays observed in coincidence with 656-keV gamma rays			511	656	820		1120	1250	1400				2160		2450		2800			
Gamma rays fitted in the decay scheme	280		511	656	820		1120	1250	1400	1480			2160		2480		2800	3000	3400	3650

rays of energy around 1700 keV in coincidence with the 656-keV gamma ray, but the peaks in this region in Fig. 4 are not well formed. In coincidence with the 820-keV gamma ray, the annihilation radiation and the 656-keV gamma ray appeared. There may be high-energy gamma rays in coincidence with the 820-keV gamma ray, but the intensity was too weak to form proper peaks. Energies of the gamma rays observed in scintillation spectrometer studies and those used in drawing the decay scheme are given in Table I.

In order to find the positron branching to the various excited states of Cd^{110}, the following technique was adopted. A composite source of Sn^{110}–In^{110} was wrapped up in a copper foil thick enough to annihilate all the positrons. The source was viewed by two 3-in.×3-in. NaI(Tl) crystals at 180° which detected the annihilation radiation in coincidence. A third 3-in.×3-in. NaI(Tl) detector at 90° to the other two, detected the gamma rays in simultaneous coincidence with the two annihilation quanta. In this way it was possible to observe all the gamma rays which followed positron emission. In this coincidence spectrum, all the gamma rays which followed the electron captures were eliminated. Such a spectrum for the decay of In^{110} is reproduced in Fig. 5. There is an intense peak at 656 keV indicating a strong positron feeding of the 656-keV state. In addition, there are peaks of weak intensity at 820 keV, and presumably also at 1120 and 1500 keV. This spectrum could be interpreted to mean that the positron decay of In^{110} feeds the 656-keV state strongly, and feeds weakly the level at 1474 keV, which de-excites with the emission of the stopover 820-keV and the crossover 1474-keV gamma rays. A level at about 1800 keV is also weakly populated by the positron decay; and this level de-excites by the emission of 656- and 1120-keV cascade gamma rays, presumably

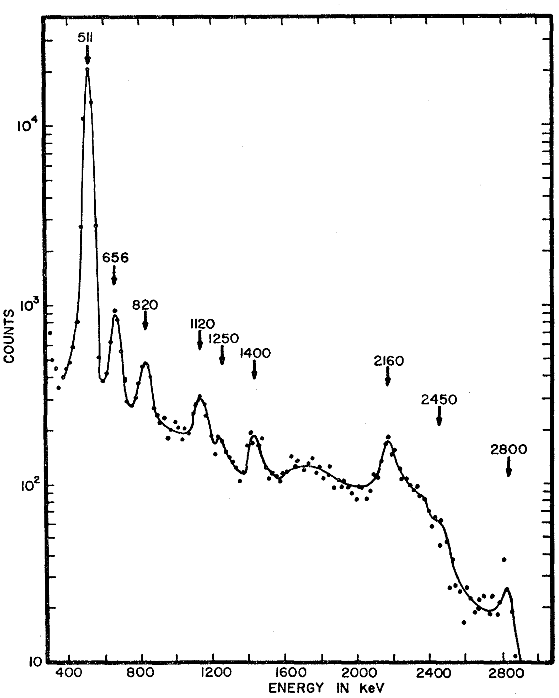

FIG. 4. Spectrum of gamma rays of In^{110} in coincidence with the 656-keV gamma ray.

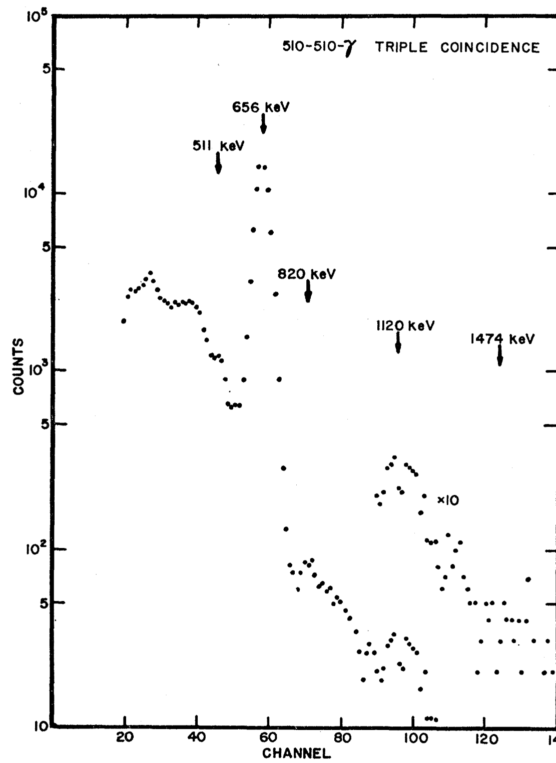

FIG. 5. Spectrum of gamma rays in simultaneous coincidence with two annihilation quanta.

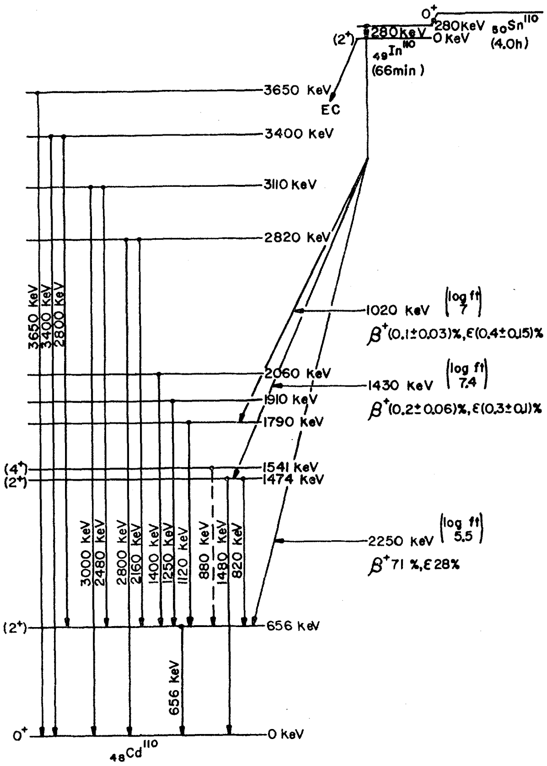

FIG. 6. A tentative decay scheme of $Sn^{110}-In^{110}-Cd^{110}$.

also a 1790-keV crossover gamma ray. From the relative intensities of the gamma rays, positron branching to these three levels can be calculated with an accuracy with which the decay scheme is known and the gamma-ray intensities are known. Due to the low intensity of positron feeding, and due to the contribution of the bremsstrahlung, the gamma-ray intensities can at best be estimated from the peaks in Fig. 5 with an accuracy of 30%. From the relative intensities of the gamma rays in Fig. 5, the intensities of the positron branching to the 656-, 1474-, and 1790-keV levels have been estimated to be in the ratio $100:0.3\pm0.1:0.12\pm0.04$. The electron-capture intensities were estimated from the theoretically calculated $K/\beta+$ branching ratios.[4] The $\log ft$ values of the decay to the 656-, 1474-, and 1790-keV levels have been estimated to be 5.5, 7.5 ± 0.3, and 7 ± 0.3, respectively.

[4] M. L. Perlman and M. Wolfsberg, Brookhaven National Laboratory Report No. BNL-485 (T-110), 1958 (unpublished).

V. DISCUSSION

The decay scheme of In^{110} is given in Fig. 6. This is based on the energy sum rule and the result of the coincidence study with the 656-keV gamma ray in the gate. It seems to us that the decay scheme is considerably more complex than what is shown in Fig. 6.

From the decay of Ag^{110m} and In^{110m}, the 2^+ and 4^+ members of the second vibrational triplet are known in Cd^{110}; the former at 1474 keV is excited in the decay of 66-min In^{110}. If one takes into account the reported gamma rays[2] from 24-sec Ag^{110}, it is plausible that the second excited state of Cd^{110}, like that of Cd^{112} and Cd^{114}, has more than three sublevels.

The $\log ft$ value of the positron decay of In^{110} (2^+) to the 1484-keV (2^+) state should be allowed, but in this work the $\log ft$ for this decay has been estimated to be 7.4, which indicates that if one assumes the correctness of 2^+ assignment to the 1474-keV state, the allowed positron decay to the second vibrational state in Cd^{110} is about 100 times retarded in comparison to the allowed decay to the first excited state. This value is somewhat larger than that quoted by Katoh *et al.*[1] Another example of retarded allowed positron decay was found in the decay of I^{122}.[5] Sakai[6] has collected five clear examples of this kind of retarded allowed beta decay. From our investigations, it seems to us that allowed beta decay to the second vibrational state of near-spherical nuclei is retarded. The magnitude of retardation seems to vary.

One of the levels proposed by us in Cd^{110} is at 2060 keV, which presumably is the first octupole vibrational level (3^-), observed in the inelastic alpha-particle scattering[7] and in the Coulomb excitation with oxygen ions.[8]

ACKNOWLEDGMENTS

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