Decay of 49-min Cd^{118} and 5.1-sec In^{118}†

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The decay properties of 49-min Cd^{118} and its daughter 5.1-sec In^{118} are established. The Cd^{118} has a low β-decay energy and seems to be an allowed transition. The In^{118} has (4.2 ± 0.4)-Mev β-decay energy, with about 15% of the decays going to the 1.22-Mev excited state of Sn^{118}, both β transitions being allowed. It is proposed that a previously identified 4.5-min In species is a high-spin isomer In^{118m} not formed in the β decay of Cd^{118} or formed directly in uranium fission.

INTRODUCTION

INTEREST attaches to the neutron-rich isotopes of cadmium and indium because of the patterns of isomerism for odd-A Cd, odd-A In, and even-A In, and because of the position of these nuclides in the fission-product spectrum. Earlier studies[1] gave evidence for Cd^{118} in equilibrium with the hard-β emitter In^{118} and mixed with 50-min Cd^{117}, and 3.0-hr Cd^{117m} and their In daughters. A half-life of about 30 min was reported for Cd^{118}, and an upper limit of 1 min for In^{118}. In addition, Duffield and Knight[2] reported 4.5-min In^{118} produced by the reaction $Sn^{119}(\gamma,p)$, and Wilhelmi and co-workers[3] reported the same species in the fast neutron bombardment of tin.

In the present study the neutron-rich isotopes of Cd with mass numbers above 114 were made by the bombardment of uranium with 14-Mev deuterons at the M.I.T. cyclotron. Decay removes the 3-min and 11-min Cd^{119} isomers and the 18-min and 2-min In^{119} isomers[4] and heavier isotopes of Cd and In. Corrections were made for the contributions[1,5] of 50-min Cd^{117} and 3.0-hr Cd^{117m}, using activities produced by neutron irradiation of 94% Cd^{116}. In general, Cd isotopes were separated from the targets, and In daughters were extracted from solutions of the Cd precursors.

CHEMICAL PROCEDURES

Deuteron fission of natural uranium (U^{238}) gives substantial yield of the fission products in the symmetric fission region.[6] Bombardments of about 15 min were carried out with 0.3-g U foils. The chemical procedure is based on complexing most interfering elements with tartrate and extracting Cd into $CHCl_3$ as the dithizone complex from a strongly basic solution.

Immediately after irradiation the U foils were dissolved in a mixture of 2 ml of conc. HCl and 0.2 ml of conc. HNO_3. The resulting solution was neutralized with KOH and diluted with 10 ml of 2M KOH containing 1 g of $NH_2OH\cdot HCl$ and 0.5 g of Rochelle salt, $KNaC_4H_4O_6\cdot 2H_2O$. After the addition of 0.5 mg of Cd^{+2} and 0.1 mg of In^{+3}, Ag^+, and Pd^{+2} carriers, the complex $CdDth_2$ was extracted with 20 ml of $CHCl_3$ containing 2 mg of diphenyl dithiocarbazone (dithizone) HDth. The Cd was back-extracted from $CHCl_3$ solution with 0.5M HCl. When solid Cd sources were required, precipitation from the final HCl solution was made with 5 ml of 4M NaCl containing 2 mg of tetraphenylarsonium chloride, giving $(\phi_4As)_2CdCl_4$. The entire procedure required 2 min.

The separation of In from its parent Cd was effected through a series of extractions. First, the tracer In and the Cd in the $CHCl_3$-HDth mixture were extracted with HBr. The resultant aqueous phase, made 8M in HBr, was then extracted with bis(2-chloroethyl) ether, bringing $HInBr_4$ into the ether layer and leaving $CdBr_4^{-2}$ in the HBr-water layer. Finally, the In was back-extracted from the ether with dilute HCl. Solid In samples were prepared by precipitating $In(OH)_3$, carrier free, from the HCl solution by the addition of KOH.[7]

EXPERIMENTAL RESULTS

The β decay of freshly separated fission Cd was followed on a 20-channel analyzer using a $1\frac{1}{2}$-in.$\times$1-in. anthracene crystal as the β detector. The lower solid line in Fig. 1 shows the count rate in those channels corresponding to 2.4–2.8 Mev, while the upper solid line corresponds to the 0.9–1.1 Mev region with the lengthening decay curve corresponding to the mixture: 3.0-hr Cd^{117m}, 50-min Cd^{117}, 1.9-hr In^{117m}, 1-hr In^{117}, In^{118}, and Cd^{118}. The calculated decay rate for a species with a 49-min half-life is shown by the broken line. Since Cd^{117}, produced by the bombardment of Cd^{116} with neutrons, shows no appreciable high-energy β activity,[1,4,5] the energetic β rays are ascribed to Cd^{118} or a short-lived

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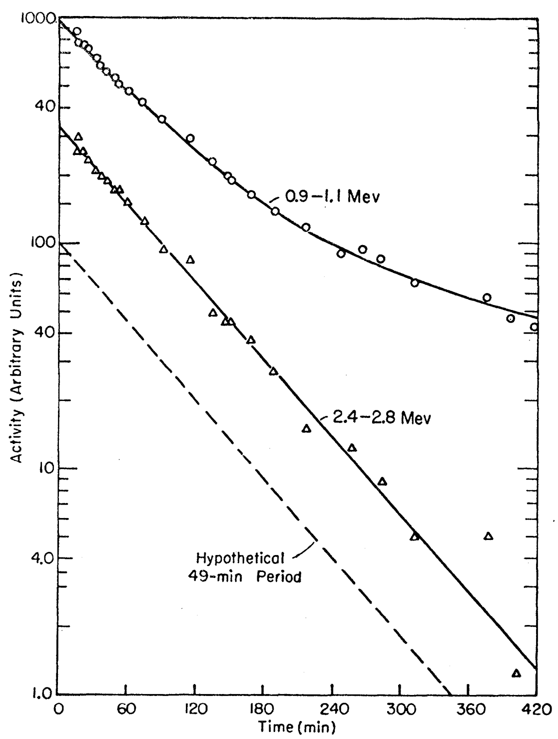

FIG. 1. Differential β analysis of Cd separated from deuteron fission products of U^{238}. o, energy channels 0.9–1.1 Mev; △, energy channels 2.4–2.8 Mev (Cd^{118} alone).

In^{118} daughter. An average of nine samples, each followed for more than seven half-lives, yields a half-life of 49.0±1.5 min for Cd^{118}.

An Al absorption curve analyzed both by Feather analysis and the *n*th-power method[8] yields a maximum β energy of 4.2±0.4 Mev for the highest energy β constituent in the fresh samples. The large error in this determination is caused by the difficulty of separating the lower energy portion of the Cd^{118} spectrum from the complex mixture of β rays from other Cd and In nuclides.

A 256-channel pulse-height analyzer was coupled with a 3-in.×3-in. NaI(Tl) crystal for γ-ray analysis. Fission Cd displayed a 1.22±0.02 Mev γ ray with a half-life of approximately 50 min. This γ ray is not in the spectrum of either of the Cd^{115} or the Cd^{117} sets of isomers. As can be seen in Fig. 2, the composite photopeak of the 1.28-Mev γ ray of 3-hr Cd^{117m} and this 1.22-Mev γ ray can be resolved on the basis of the different decay rates.

On the basis of nuclear energetics,[9] it is expected that the Q^{β} for the transition Cd^{118} to In^{118} will be about 1 Mev whereas the transition of In^{118} to Sn^{118} will be about 4 Mev. It is expected, therefore, that the 1.22-Mev γ ray and 4.2-Mev β ray are associated not with Cd^{118}, but with its In^{118} daughter. Assuming the β decay of In^{118} to be an allowed transition, the half-life of In^{118} was predicted to be approximately 7 sec.

To observe the radiations associated with In^{118}, free of Cd^{118}, the species $HInBr_4$ was extracted with bis(2-chloroethyl)ether from an aqueous HBr solution ($\sim 8M$) of fresh fission Cd. Immediate counting of the organic phase revealed that both the energetic β rays and the 1.22-Mev γ rays emanated from the In fraction. The average of 13 experiments in which the β-decay rate was observed by a plastic scintillator coupled to a count-rate meter with a graphical readout gave a half-life of 5.1±0.5 sec for the short-lived In.

The parent-daughter relationship between the 49-min Cd^{118} and the 5.1-sec In was confirmed by a series of experiments in which In was extracted from fission Cd over a period of several hours. By means of an automatic timing device approximately 5 sec after each extraction, the organic phase was counted for 4.27 sec; 46.9 sec later another count of 4.27 sec duration was made. Subtracting each second reading from the first eliminates the activity due to long-lived species and permits the measurement of the decrease in initial 5.1-sec In activity. The accumulated number of short-lived In β counts in the first 4.27 sec fell exponentially with the time after separation of Cd, the slope corresponding to a half-life of 48±4 min. This confirms the genetic relation, as expected from Fig. 1, for the precursor of the hard β emitter.

The fraction of β decays of 5.1-sec In^{118} giving rise to the 1.22-Mev γ ray was determined by β-γ coincidence in the mixture of Cd isotopes obtained from fission

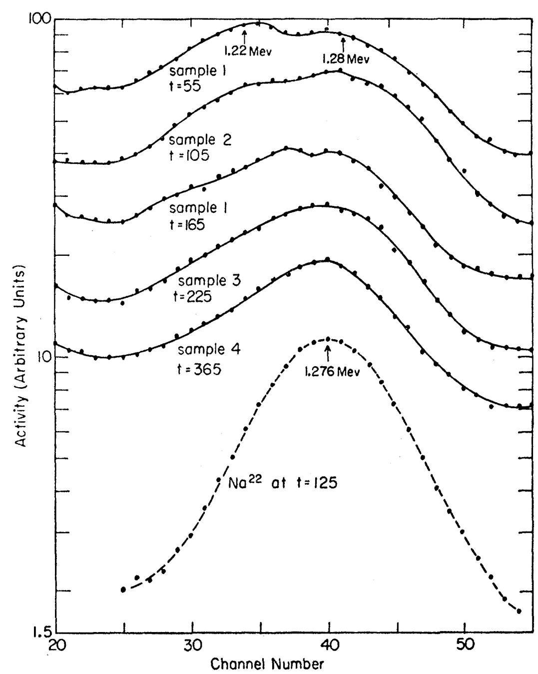

FIG. 2. Part of the γ spectrum of Cd from fission with In daughters, with Na^{22} calibration (1.276 Mev).

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products. An Al absorber of 962 mg/cm^2 was used to eliminate β rays from extraneous species; this corresponds to the fraction 0.65 of the estimated range of the 3.0-Mev β in coincidence with the 1.22-Mev γ and to the fraction 0.45 of the range, 2120 mg/cm^2, of the 4.2-Mev β. Using an estimated absorption curve for allowed transitions,[8] the ratio of β-counting efficiencies was calculated to be 0.5, and the counting efficiency for the 1.22-Mev γ was taken as the same as for Na^{22}, namely 0.062. The observed coincidence rate, corrected for chance coincidence, was 4.3×10^{-3} of the observed β-counting rate and decayed with approximately the 49-min period. It is thus calculated that the β branching to the 1.22-Mev level in Sn^{118} is 0.15. This number may be high by 0.05 or low by 0.1 because of the rather large uncertainty in the ratio of counting efficiency of the two β branches.

A search for the In^{118} of 4.5-min half-life[2,3] among the In isotopes formed in the decay of fission Cd or found in the In fraction in fission yielded negative results. However, In species of 18-min and 2-min periods were observed. These are believed to be associated with the 119 chain.[4]

DISCUSSION OF RESULTS

An even mass assignment is taken for the chain 49-min Cd $\rightarrow$ 5.1-sec in $\rightarrow$ stable Sn on the basis of the low total energy of Cd decay, the high energy of the In decay, and the alternation in half-life. The next even Cd isotope, Cd^{120}, is expected[9] to have substantially higher decay energy and thus shorter life. The identification of the 1.22-Mev γ ray of the 5.1-sec In with that observed[10,11] in Coulomb excitation of Sn^{118} is in accord with the assignment of $A=118$. The decay data for this chain are given in Fig. 3.

It was impossible to determine the β-decay energy of Cd^{118} in the mixture of Cd activities found in fission (especially 50-min Cd^{117}). The β-decay energy is estimated as 0.8 Mev from β systematics.[9] This corresponds to $\log ft=4.6$ corresponding to an allowed transition to 5.1-sec In^{118}. Since Cd^{118} certainly has the ground state 0^+, the 5.1-sec In^{118} is either 0^+ or 1^+. The β decay of In^{118} shows it to be 1^+.

The failure to find the 4.5-min In^{118} in fission suggests that this species is a high-spin isomer not formed in the β decay of zero-spin 49-min Cd^{118}. The species In^{118} is not expected to be formed in appreciable yield as a primary fission product.[12] The decay was characterized[2] as proceeding by $\sim$1.5-Mev β rays (absorption analysis) plus γ radiation. The β radiation is probably a composite of transitions to the 5^+ and 4^+ levels of Sn^{118} identified by McGinnis,[13] at 2.25 and 2.50 Mev above ground state. The $\log ft$ for the pair of β transitions is $\sim$4.7,

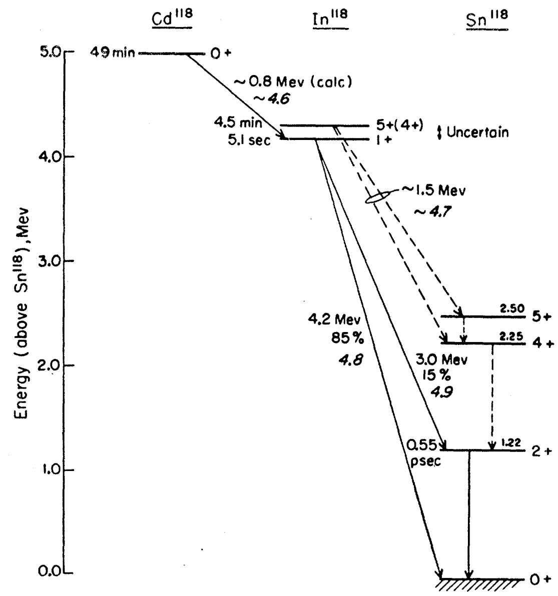

FIG. 3. Decay schemes for 49-min Cd^{118}, 5.1-sec In^{118}, and 4.5-min In^{118m}.

which would imply that the 4.5-min In^{118} is 4^+ or 5^+. A spin of 5^+ for 4.5-min In^{118} is in accord with the available data,[14] and in agreement with information for other odd-odd nuclei in this region.[15] For In^{114} and In^{116} the 5^+ level lies above the 1^+ level,[15] the latter also being the ground state for In^{112}. In Fig. 3 the 5^+ level is placed above the 1^+ level, implying that the energy of the 5^+ level is probably more than 4.2 Mev above the ground state of Sn^{118}.

The main decay mode of 5.1-sec In^{118} (4.2 ± 0.4 Mev) goes to ground state Sn^{118} with $\log ft=4.8$. The branch to the 1.22-Mev level has $\log ft=4.9$. These two values require the In^{118} level to be 1^+. The 1.22-Mev level in Sn^{118} is reported[10,11] to have a lifetime of 0.55 psec [1 picosecond (psec) $=10^{-12}$ sec].

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