Energies and Half-Lives of Isomeric Transitions in Sn^{115} and Cd^{109}†

A. L. McCarthy and T. W. Conlon*
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey
(Received 20 December 1965)

The energies and half-lives of isomeric transitions in Sn^{115} and Cd^{109} have been measured in pulsed proton beam bombardments of natural In and Ag at 17.5 MeV. The isomeric gamma rays were detected with a lithium-drifted germanium detector; time and energy information were obtained with the use of a 4096-channel two-dimensional analyzer. The values obtained were: Sn^{115}: 115.9±1 keV, 100.7±2 keV, 498.0±1 keV; 166.4±10 μsec; and Cd^{109}: 263±5 keV, 206±5 keV; 10.4±1 μsec. The gamma rays are quoted in their probable order of emission.

INTRODUCTION

THE 160-μsec isomeric transition in Sn^{115} was first observed by Duffield and Vegors[1] in (γ,n) reactions on natural Sn, but they made no assignment. Ivanov *et al.*[2] have studied the transition in detail. They produced Sn^{115} in the metastable $\frac{11}{2}-$ state by the (p,n) reaction on natural In which is 95.72% In^{115}, and observed three gamma rays in cascade. McCarthy *et al.*[3] have observed the same isomeric transitions where the $\frac{11}{2}-$ state is formed in the reaction $In^{115}(d,2n)Sn^{115}$, again on natural In. In none of these experiments were the two low-energy gamma rays resolved, but the assignments made by both groups,[2,3] namely that the cascade consists of an $M2$ transition from the $\frac{11}{2}-$ state to a $\frac{7}{2}+$ state about 100 keV lower in excitation energy followed by a second gamma ray of similar energy and a third with energy about 500 keV, is confirmed from the location of the states of Sn^{115} in the reaction $Sn^{114}(d,p)Sn^{115}$ by Schneid *et al.*[4] They find the states given in Table I. In the present work the three gamma rays have been completely resolved by the use of a lithium-drifted germanium detector of volume 7 cm^3 and depth about 9 mm.

The 11-μsec isomer reported in Ref. 3 following the deuteron bombardment of naturel Ag, and also by Brandi *et al.*[5] from (γ,n) reactions on Cd, has been observed here in the pulsed proton-beam bombardment of natural Ag. The half-life of this isomer has been measured to be in agreement with the previous values. The present data, together with those previously known, strongly suggest the assignment of the isomer to Cd^{109} as discussed below.

EXPERIMENTAL

The 17.5-MeV pulsed proton beam from the Princeton University FM cyclotron having a 25-μsec duration and 300–3000 μsec interval has been used to bombard thick targets of natural Ag and In. A two-dimensional analyzer with an associated electronics system similar to that described in Ref. 3 was utilized to measure the half-lives. The energy measurements were made simultaneously. The energy resolution in these runs is inferior to that obtained with source gamma rays because of the problem of amplifier recovery from overload signals of prompt gamma rays which occur during the beam bombardment. The resolution for the 661.6-keV Cs^{137} gamma ray was typically 4.8 keV. In the case of Sn^{115} the resolution was about 8.5 keV (full width at half maximum); and for the silver bombardment 16-keV resolution was obtained. In the latter case the poor resolution was due to the use of very sharply double *RC* clipped pulses for a more rapid restoration of the baseline. The Li-Ge detectors used for all the measurements were fabricated by one of us (T.W.C.).

The circuits used for making the half-life measurements were used in conjunction with a proton detector to observe scattered protons from a thin Ta foil in order to find the time distribution of protons in the beam. It was determined that the beam pulses cut off relatively sharply and that the counting of the isomeric gamma rays could be started some 10 μsec after the end of a 25-μsec beam pulse without interference from prompt events due to residual beam. The residual beam after 10 μsec was less than one part in 10^6 of the beam during the pulse, and thus, all the gamma rays observed are due to delayed events.

Energy calibrations were made using sources of Co^{57}, Hg^{203}, and Cs^{137}, and also the 511-keV annihilation radiation produced in the target. In the case of Ag, gamma rays from Co^{57} and Cs^{137} were detected at the same time as those from the isomer in order to overcome problems of gain shifting due to the rapidly changing intensity of the isomeric source.

Table I. Levels of Sn^{115} found in the reaction $Sn^{114}(d,p)Sn^{115}$[a].

J^π	E(keV)
11/2−	720
$\frac{7}{2}+$	600
$\frac{5}{2}+$	490

[a] Reference 4.

† This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
* Recipient of a N.A.T.O. Award.
[1] R. B. Duffield and S. H. Vegors, Phys. Rev. **112** 1958 (1958).
[2] E. Ivanov, A. Alevra, D. Plostinaru, M. Martalogu, and R. Dumitrescu, Nucl. Phys. **54**, 117 (1964).
[3] A. L. McCarthy, B. L. Cohen, and L. H. Goldman, Phys. Rev. **137**, B250 (1965).
[4] E. J. Schneid, A. Prakash, and B. L. Cohen (private communication).
[5] K. Brandi, R. Engelmann, V. Hepp, E. Kluge, H. Krehbiel, and U. Meyer-Berkhout, Nucl. Phys. **59**, 33 (1964).

RESULTS AND DISCUSSION

Indium

Figure 1 shows the energy spectrum of isomeric gamma rays from the reaction $In^{115}(p,n)Sn^{115}$. Superimposed on the same figure are the spectra of the calibration sources of Co^{57} and Cs^{137}. The energies of the gamma rays have been found to be 100.7±2 keV, 115.9±1 keV, and 498.0±1 keV. The errors have been assigned on the basis of consistency between independent runs. The values obtained by Ivanov *et al.*[2] were 107, 120, and 500 keV, respectively.

In the spectrum the peak with the highest channel number is due to a pulser and this pulser has been used to normalize the live-time of the analyzer as discussed in Ref. 3. Figure 2 shows the decay curves for the two low-energy gamma rays; the data have been corrected for background and live-time. The values of the half-life from the two peaks agree to within 3% and the mean result is 166.5±10 μsec as compared to 159±1 μsec in Ref. 2. The value extracted for the 498-keV peak is similar but the result is not so accurate because of the proximity of the 511-keV peak.

Silver

Figure 3 shows the energy spectrum of gamma rays following the proton bombardment of natural Ag. In this spectrum the Co^{157} 122-keV gamma ray and the 511-keV annihilation radiation also appear. The energies of the gamma rays from Ag are 206±5 keV and 263±5 keV and these values have been averaged over many similar spectra. The linearity of the system has been checked using a precision mercury pulser. In Fig. 4 we can see the decay curves for each gamma ray, and these points have been corrected for the background and for live-time. The half-life in each case is 10.4 μsec. The values obtained for the energies and half-life by Brandi *et al.*[5] were 199 keV, 257 keV, and 10.4 μsec; and by McCarthy *et al.*, were 217 keV, 273 keV, and 10.8 μsec.

The single-particle estimates of the lifetime for the energies observed predicts that the isomeric transition is $M2$. In this part of the periodic table the most likely level ordering to produce such a transition is to have an $h_{11/2}$ level above a $g_{7/2}$ level. The systematics of the positions of the low-lying $\frac{11}{2}-$ and $\frac{7}{2}+$ levels in the isotopes of Pd, Cd, and Sn[6,7,4] are shown in Fig. 5. The known isomeric $M2$ transitions between the $\frac{11}{2}-$ and $\frac{7}{2}+$ states are shown on the diagrams by downward going arrows, together with the half-lives. When the $\frac{7}{2}+$ level is above the $\frac{11}{2}-$ level there is usually no $M2$ isomer since in general there are other levels to which the $\frac{7}{2}+$ level can decay. The $M2$ transition in

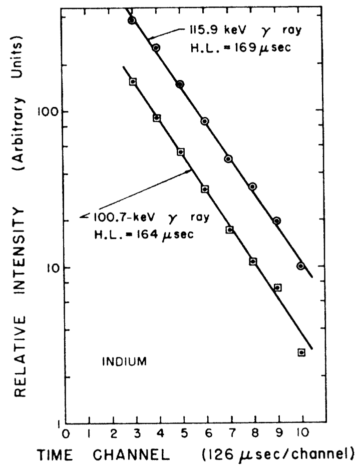

FIG. 2. Decay curves for isomeric gamma rays from Sn^{115}. Corrections have been made for background and analyzer live-time. The mean half-life is 166.5±10 μsec.

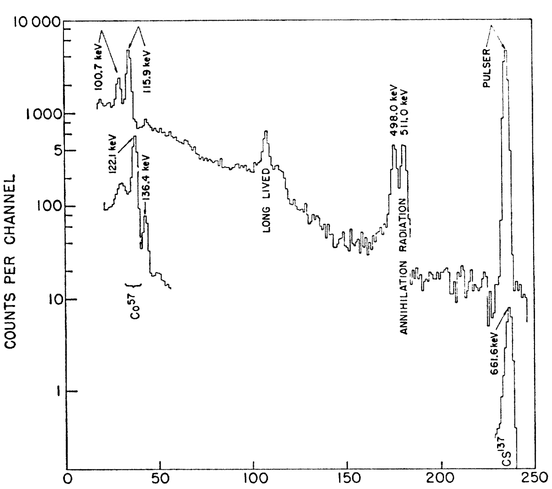

FIG. 1. Energy spectrum of gamma rays of Sn^{115} following the proton bombardment of natural In. Also shown are the gamma rays from Co^{57} and Cs^{137} calibration sources. The high-energy peak is a pulser.

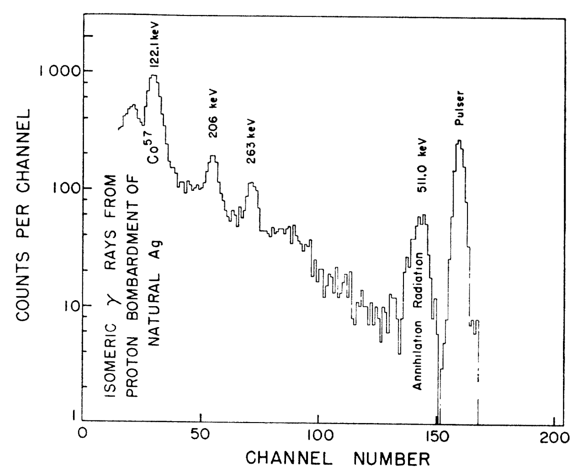

FIG. 3. Energy spectrum of gamma rays of Cd^{109} following the proton bombardment of natural Ag. In the same spectrum can be seen the Co^{57} and Cs^{137} calibration source peaks and a pulser.

[6] B. Cujec, Phys. Rev. **131**, 735 (1963).
[7] B. Rosner, Phys. Rev. **136**, 664 (1964).

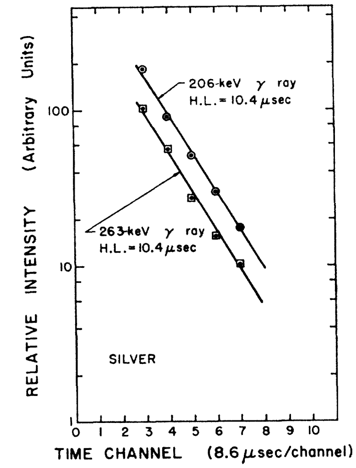

FIG. 4. Decay curves for isomeric gamma rays from Cd^{109}. Corrections have been made for background and for analyzer live-time. The mean half-life is 10.4 ± 1 μsec.

Pd^{103} has been sought in pulsed beam measurements[8] in which the shortest half-lives observable were about 5 μsec, but not observed. The half-life must therefore be less than 5 μsec, and indeed the single-particle estimate is about 1.0 μsec. Similarly, for Sn^{113} the single-particle estimate for the 670-keV $\frac{11}{2}-$ to $\frac{7}{2}+$ transition is about 0.1 μsec. The trend of the $\frac{11}{2}-$ curve for the Cd isotope suggests that a 10-μsec isomer would be reasonable for Cd^{109} and possibly for Cd^{107}.

Several auxiliary experiments were done in order to determine the reaction producing this isomer.

In order to eliminate the possibility that the isomer is formed in Cd^{106} or Cd^{108}, the beam energy at the Ag target was reduced to agout 9 MeV using a carbon absorber. The isomeric gamma rays were observed with strengths comparable to that observed with 17.5 MeV bombarding energy. However, the Q values for the reaction $Ag^{109}(p,2n)Cd^{108}$ is -8.19 MeV and for $Ag^{107}(p,2n)Cd^{106}$ is -9.76 MeV so that we may exclude the possibility of the isomer being in either the Cd^{106} or Cd^{108} nuclei. In an elastic scattering experiment of protons on natural Ag we have not observed states at energies which would explain the occurrence of the isomer in Ag^{107} or Ag^{109}. The (p,n) cross section is then the only one which would explain the fairly strong excitation of this isomer and we therefore conclude that the isomeric state is in Cd^{107} or Cd^{109}. This conclusion together with that obtained by Brandi *et al.*[5] that the isomer must be assigned to Cd^{109} or Ag^{109} strongly support its assignment to Cd^{109}.

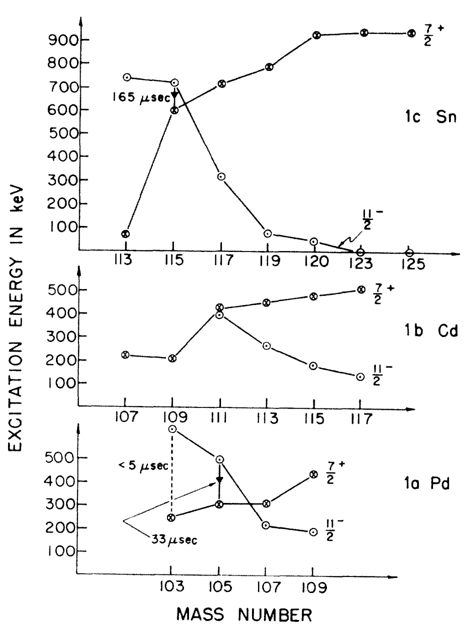

FIG. 5. Systematics of low-lying 11/2− and $\frac{7}{2}+$ levels in the isotopes of Pd, Cd, and Sn. (a) Pd, Ref. 6. (b) Cd, Ref. 7. (c) Sn, Ref. 4.

TABLE II. Conversion coefficients and predictions of relative gamma-ray intensities in Cd^{109}.

E_γ (keV)	Conversion coefficients		Ratio $I(263)/I(206)$
	If 263-keV transition isomeric		
263	$M2$	0.125	
206	$M1$	0.057	$1.057/1.125=0.94$
	If 206-keV transition isomeric		
263	$M1$	0.028	
206	$M2$	0.290	$1.290/1.028=1.26$

The order of emission of the gamma rays has been determined by measuring the relative intensities of the two gamma rays and comparing this measured ratio with the ratio of intensities calculated for the two possible orders of emission using the internal conversion coefficients of Sliv and Band.[9] The observed ratio of 0.57 from the data has to be corrected for detector efficiency. This factor is obtained from observations of γ rays in cascades of known multipolarity in Ta and Hf.[10] The efficiency factor between the energies is 1.57, giving a true relative intensity $I(263)/I(206)=0.90$. The predicted values for this ratio for the two alternatives are shown in Table II. The measured value is in good agreement with the 263-keV gamma rays being the $M2$ isomeric transition followed by a 206-keV, $M1$ transition.

The level scheme of Cd^{109} [11] can be easily modified to incorporate this data inserting an $\frac{11}{2}-$ state at 469 keV which decays to the known $\frac{7}{2}+$ state at 205 keV and thence to the $\frac{5}{2}+$ ground state.

[8] A. L. McCarthy, Ph.D. thesis, University of Pittsburgh, 1964 (unpublished).

[9] L. A. Sliv and I. M. Band, in *α-, β-, and γ-Ray Spectroscopy* edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1965).

[10] T. W. Conlon, Bull. Am. Phys. Soc. (to be published).

[11] M. Nozowa, Nucl. Phys. **36**, 411 (1962).