Beta Decay of Cd^{115m}†

O. E. JOHNSON AND W. G. SMITH
Physics Department, Purdue University, Lafayette, Indiana
(Received June 22, 1959)

The decay of Cd^{115m} was studied by using NaI(Tl) scintillation counters and a 4π beta scintillation spectrometer. The following gamma rays were observed: 0.485±0.007, 0.935±0.014, 1.14±0.017, and 1.29±0.019 Mev. The 0.485- and 0.935-Mev gammas were found to be in coincidence. There were no gammas in coincidence with the 1.29-Mev gamma. The end-point energy of the ground-state beta transition was determined to be 1.631±0.016 Mev. The shapes and end-point energies of the beta groups in coincidence with the 0.935- and the 1.29-Mev gammas were measured. The former has a $\Delta I=2$, yes, character; and the latter appears to have an allowed or statistical shape; the end-point energies are 0.687±0.008 Mev and 0.335±0.010 Mev, respectively.

INTRODUCTION

CADMIUM-115M beta decays, with a half-life of 43–44 days, to In^{115}. The ground-state spins of Cd^{111} and Cd^{113} have been directly determined to be $\frac{1}{2}$; from these measurements it is inferred that the spin of Cd^{115} is also $\frac{1}{2}$. According to the shell model the only spin $\frac{1}{2}$ orbital available between the closed neutron shells at 50 and 82 is $s_{\frac{1}{2}}$, therefore it is assumed that the parity of these ground states is even. There has been no observation of radiations which would indicate the presence of an isomeric transition from Cd^{115m} to the Cd^{115} ground state. The energy of this transition would be ~0.150 Mev according to the beta-decay energies of the two states.[1] The beta spectrum of Cd^{115m} has been measured by Hayward[1]; and the following groups were observed: 1.61 Mev, ~98%; 0.65 Mev, ~2%; and 0.33 Mev, weak. The fact that the 0.150-Mev isomeric transition does not compete with the 1.6-Mev beta group requires that the former be an $E5$ multipole.[2] Assuming that the ground-state configuration of Cd^{115} is $\frac{1}{2}+$, the isomeric state must be $11/2-$. The $h_{11/2}$ orbitals of the shell model are filled after the closed shell at 50 neutrons and they could be expected to give low-lying excited states. Engelkemeir[3] made an absorption measurement of the beta particles in coincidence with a 0.94-Mev gamma ray; a beta group with an end-point energy of 0.8 Mev and relative intensity of ~1.4% was observed. Gill, Mandeville, and Shapiro,[4] also with an absorption measurement, observed a 0.38-Mev beta group with a relative intensity of ~1% in coincidence with a 1.30-Mev gamma ray. The 1.61-Mev beta group is not in coincidence with any gamma rays.[3,4] Using the above relative intensities for the 1.61-, 0.65-, and 0.33-Mev beta groups, the following $\log f_0t$ values can be calculated: 8.8, 9.2, and 8.3, respectively. The most complete gamma study has been made by Varma and Mandeville.[5] They observed the following gamma rays: 0.485, 0.935, and 1.30 Mev; with relative intensities of 1.0, 7.4, and 3.1, respectively. The 0.485- and 0.935-Mev gammas were shown to be in coincidence. The 0.485-Mev gamma is less intense than the 0.935-Mev radiation, therefore it is assumed that the former is the upper transition in the cascade. Varma and Mandeville also made a $\gamma-\gamma$ angular correlation measurement of the 0.485–0.935 cascade and found the correlation to be essentially isotropic. The ground-state spin of In^{115} has been directly measured as 9/2. The only spin 9/2 shell model orbital available in the region of $Z=49$ is the $g_{9/2}$; therefore even parity is assumed for the In^{115} ground state. The 0.485–0.935 Mev gamma correlation results of Varma and Mandeville can be fitted with a $9/2(D)7/2(D)9/2$ sequence. However, if the radiations are not pure multipoles, other spin possibilities exist for the two excited states.[5] The decay scheme of Cd^{115m} proposed by Varma and Mandeville is shown in Fig. 1. The spin and parity assignments of the 0.935 level, $7/2+$; the 1.30 level, $11/2+$; and the 1.42 level, $9/2+$; are compatible with the $\log f_0t$ values of the beta groups. This scheme incorporates all of the above listed results. The levels at 0.935, 1.30, and 1.42 Mev, and others, in In^{115} have also been observed by (γ,γ'), (n,n'), $(\alpha,\alpha'\gamma)$, (p,p'), and $(n,n'\gamma)$ reactions.[6–16]

According to this scheme, and corroborated by the $\log f_0t$ of 9.2, the 2% beta group populating the 0.935-Mev level should be a once-forbidden, unique transition: $\Delta I=2$, yes. The possibility of measuring the shape of this group in coincidence with the 0.935-Mev gamma

† Work supported in part by the U. S. Atomic Energy Commission.

1 R. W. Hayward, Phys. Rev. **87**, 202(A) (1952).
2 M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
3 D. Engelkemeir, Argonne National Laboratory Report ANL-4526, 92 (unpublished).
4 Gill, Mandeville, and Shapiro, Phys. Rev. **80**, 284 (1950).
5 J. Varma and C. E. Mandeville, Phys. Rev. **97**, 977 (1955).
6 Burkhardt, Winhold, and Dupree, Phys. Rev. **100**, 199 (1955).
7 Schillinger, Waldman, and Miller, Phys. Rev. **83**, 320 (1951); **81**, 318(A) (1951).
8 W. C. Miller and B. Waldman, Phys. Rev. **75**, 425 (1949).
9 Korsunsky, Walter, Iranov, Zypkin, and Ganenko, J. Phys. U.S.S.R. **1**, 129 (1943).
10 Elliot, Hicks, Beghian, and Halban, Phys. Rev. **94**, 144 (1954).
11 A. A. Ebel and C. Goodman, Phys. Rev. **93**, 197 (1954).
12 Martin, Diven, and Taschek, Phys. Rev. **93**, 199 (1954); **92**, 1096(A) (1953).
13 R. R. McLeod, Phys. Rev. **100**, 1265(A) (1955).
14 R. D. Sharp and W. W. Buechner, Bull. Am. Phys. Soc. **2**, 179 (1957).
15 Scherrer, Allison, and Faust, Phys. Rev. **96**, 386 (1954).
16 Day, Johnsrud, and Lind, Bull. Am. Phys. Soc. Ser. II, **1**, 56 (1956).

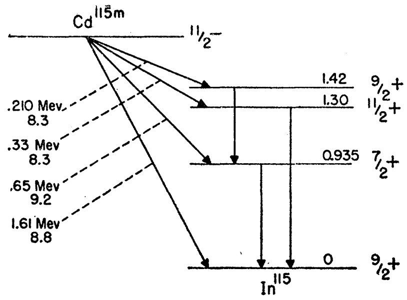

FIG. 1. Decay scheme of Cd^{115m} proposed by Varma and Mandeville.[5]

ray prompted the present study. In addition, the somewhat large $\log f_0t$ value, 8.3, of the beta transition to the 1.3-Mev level made a study of this group of interest.

INSTRUMENTATION

A schematic diagram of the 4π beta-ray scintillation spectrometer used in this study is shown in Fig. 2. The spectrometer system is basically the same as the one developed and described by Johnson, Johnson, and Langer[17] and extended in application by Robinson and Langer.[18] The source, mounted on a thin Zapon film, is centered between two cylindrical Pilot-*B* plastic phosphors each 1.5 inches in diameter $\times$0.625 inches thick. The phosphors were optically coupled with Dow Corning 200 silicone fluid to the 6292 photomultiplier tubes. The beta pulses from the gain of ten preamplifiers go to an addition circuit, gain one, and then into the *A*-61 amplifier of an RCL 256-channel analyzer. The resolution obtained for the 0.624-Mev internal conversion line of Cs^{137} was between 10.5 and 11% for all experimental runs. The linearity and stability of the spectrometer was checked by measuring 4 conversion electron lines with energies between 61 kev and 974 kev and by using a precision mercury relay pulser. It is necessary to make finite resolution corrections when using a scintillation spectrometer to measure beta spectra. The method of Palmer and Laslett[19] was used, whenever the correction was not negligible, in all of the present work. The performance of the instrument was evaluated by measuring the beta spectra of W^{185} and Pm^{147}. The end-point energy of W^{185} is 430 kev and the Fermi plot was linear down to $<$90 kev. Pm^{147} has an end point of 225 kev and the Fermi plot was linear down to $<$40 kev.

In order to study beta spectra in coincidence with gamma rays a cylindrical 3$\times$3-in. NaI(Tl) crystal was placed adjacent to the beta phosphors with its axis perpendicular to the axis of the beta phosphors. The gamma pulses after amplification were analyzed in a

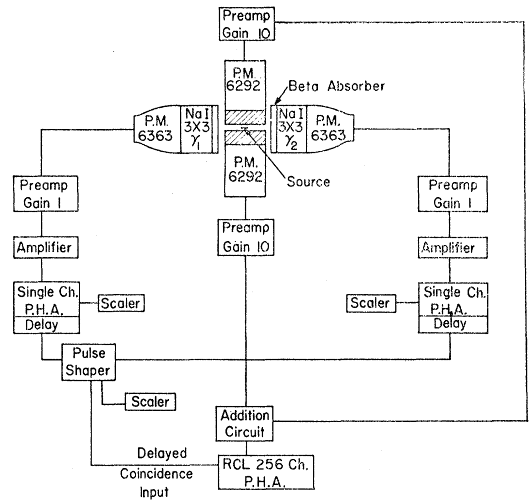

FIG. 2. Schematic diagram of 4π beta-ray scintillation spectrometer.

single channel differential discriminator, fed into a variable time delay, then into a pulse shaper, and finally into a delayed coincidence input gate of the 256-channel analyzer. The resolving time of the latter is $\sim$1.5 μsec. The response of this system to a beta spectrum in coincidence with a gamma ray was checked using Ce^{141}. This isotope has a 30% beta group, end-point energy of 440 kev, in coincidence with a 142-kev gamma ray. The Fermi plot was linear down to 175 kev where a beta group of an impurity of Ce^{144} contributed to the beta spectrum. The relative intensities of the two beta groups of Cd^{115m} on which beta-gamma coincidence measurements were made are 1%. In order to increase the rate of data accumulation a second 3$\times$3-in. NaI crystal was placed opposite the first and pulses from both "gamma-channels" were fed into the pulse shaper.

The gamma spectrum of Cd^{115m} was measured with a 3$\times$3-in. NaI(Tl) crystal with a 0.25-in. Lucite absorber adjacent to the crystal to prevent beta particles from entering. The source to crystal distance was 10 cm. The resolution with this apparatus was 8.5% for Cs^{137}. The gamma-gamma coincidence measurements were made using two 3$\times$3-in. NaI(Tl) crystals with their axes perpendicular. Lead shielding was placed between the crystals to reduce false coincidences arising from scattered gammas. The output of one NaI(Tl) crystal was amplified and fed into a single channel differential discriminator. The single channel analyzer was set to accept a certain fraction of those pulses in one of the full energy peaks, the output pulses were shaped and fed to the delayed coincidence input of the 256-channel analyzer. The output of the second NaI(Tl) crystal was fed directly into the 256-channel analyzer. The coincident gamma-ray spectrum was measured in the latter analyzer.

[17] Johnson, Johnson, and Langer, Phys. Rev. **102**, 1142 (1956).
[18] R. L. Robinson and L. M. Langer, Phys. Rev. **109**, 1255 (1958).
[19] J. P. Palmer and L. J. Laslett, Iowa State College Report ISC-174, December, 1950 (unpublished).

EXPERIMENTAL RESULTS

The Cd^{115m} source material used in this study was obtained from Oak Ridge National Laboratory. It was produced by an (n,γ) reaction on Cd^{114}.

The gamma-ray spectrum of Cd^{115m} is shown in Fig. 3. The prominent photopeaks are at 0.088±0.002, 0.485±0.007, 0.935±0.014, 1.14±0.017, and 1.29 ±0.019 Mev. The energy calibration was made using well-known gamma radiations. The resulting least-squares fitted calibration line gave internally consistent energies for the calibration gamma rays to better than ±0.5%. The errors in the gamma energies are estimated from the uncertainties in calibration and in locating the peak positions which are superimposed on the continuous bremsstrahlung distribution. The relative intensities of the gamma rays did not change after a cadmium chemical separation was performed indicating that only cadmium activities were present. The 0.088-Mev gamma is attributed to Cd^{109}, 470 day half-life, which would be produced by an (n,γ) reaction on stable Cd^{108}. There is no 1.14-Mev gamma ray included in the level scheme shown in Fig. 1. The intensity of the 1.14-Mev gamma relative to the known Cd^{115m} gammas did not appear to change over a period of 1.5 half-lives. Several levels between 1.0 and 1.2 Mev in In^{115} have been observed by (γ,γ'), (n,n'), $(\alpha,\alpha'\gamma)$, (p,p'), and $(n,n'\gamma)$ reactions, and it is possible that a level at 1.14 Mev in In^{115} is populated by a Cd^{115m} beta transition. The energies agree well with those previously reported; see Fig. 1. An upper limit of 2.5% can be set on the intensity of a 0.12-Mev gamma ray relative to the 0.935-Mev gamma.

Two γ-γ coincidence measurements were made; one gating on the 0.935-Mev photopeak and the other gating on the 1.29-Mev photopeak. Only the 0.485-Mev gamma was found to be in coincidence with the 0.935-Mev gamma. No gammas were observed in coincidence with the 1.29-Mev radiation.

The gross beta spectrum with no coincidence requirements was measured. The Fermi plot was found to have an almost continuous concave-up curvature. The non-linearity in the Fermi plot is due to the superposition of inner beta groups, and sum pulses from the inner beta groups and Compton electrons from the prompt gamma transitions which follow. The high-energy end of the Fermi plot had only a very slight curvature and the 8 points with $3.492 \leq W \leq 3.912$ were least squares fitted to a straight line to obtain the end-point energy. The latter was found to be 1.631±0.016 Mev. The error limits were determined from the deviations of the experimental points due to statistical counting fluctuations from the least-squares fitted line; and from the estimated uncertainty of the energy calibration, ±1%.

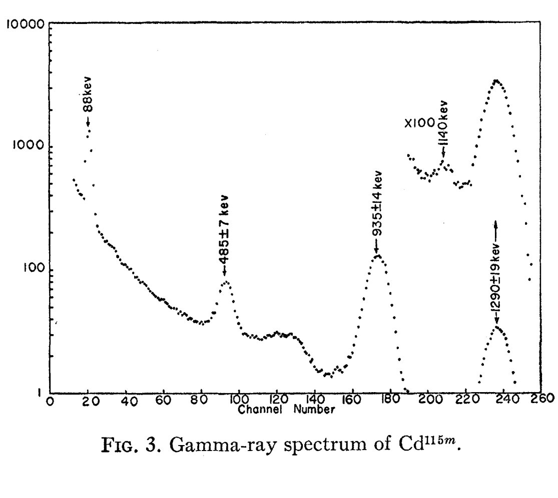

FIG. 3. Gamma-ray spectrum of Cd^{115m}.

A conventional Fermi plot of the beta group in coincidence with the 0.935-Mev gamma is shown at the top of Fig. 4. The same experimental data when corrected with the once-forbidden unique shape factor, $\alpha_1 = q^2L_0 + 9L_1$ is shown at the bottom of Fig. 4. The body correction for finite resolution was negligible, <1%. The 3 highest energy points were end-point corrected. The 8 points with $1.690 \leq W \leq 2.111$ were least squares fitted to obtain the end-point energy, 0.687±0.008 Mev. The error was determined as described above. The statistical counting errors are indicated by bars on a few points. The arrow indicates the position of the end point of the next lower energy beta group, 0.335 Mev. The latter group is in coincidence with the 1.29-Mev gamma ray. The α_1-corrected Fermi plot of the 0.687-Mev group would be expected to deviate upward from linearity at energies less than 0.335 Mev because the single-channel analyzer would accept some of the pulses in the Compton distribution of the 1.29-Mev gamma ray. It is clearly seen from the Fermi plots in Fig. 4 that 0.687-Mev beta transition is of the type $\Delta I = 2$, yes.

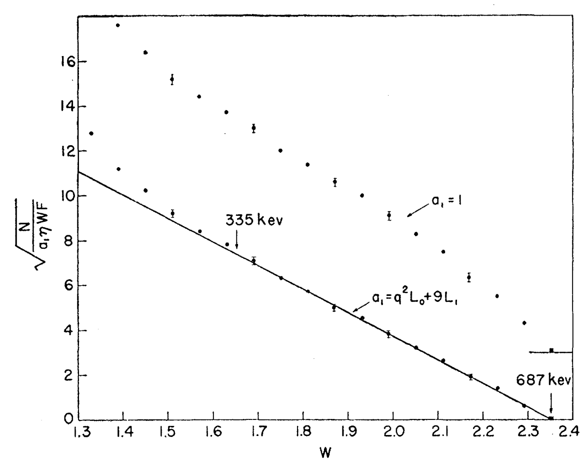

FIG. 4. Conventional and corrected Fermi plots of the beta spectrum in coincidence with the 0.935-Mev gamma ray.

A conventional Fermi plot of the beta group in coincidence with the 1.29-Mev gamma is shown in

Fig. 5. No body corrections were made to this spectrum; however, the last 3 points were end-point corrected. The end-point energy, 0.335±0.010 Mev, was obtained from the line least squares fitted to the 9 points with $1.205 \leq W \leq 1.522$. Statistical counting error bars are shown on a few points. An experimental shape factor, $S_n = N/\eta WF(W_0 - W)^2$, is shown in Fig. 6. The shape factor for this group is consistent with a statistical distribution. The arrow in Fig. 5 shows the position of the end point, ~0.21 Mev, of the beta group which populates the 1.42-Mev level. If a transition from the 1.42-Mev level to the 1.29-Mev level did occur, the Fermi plot of the betas in coincidence with the 1.29-Mev gamma would deviate from linearity for energies lower than ~0.21 Mev. According to Gill, Mandeville, and

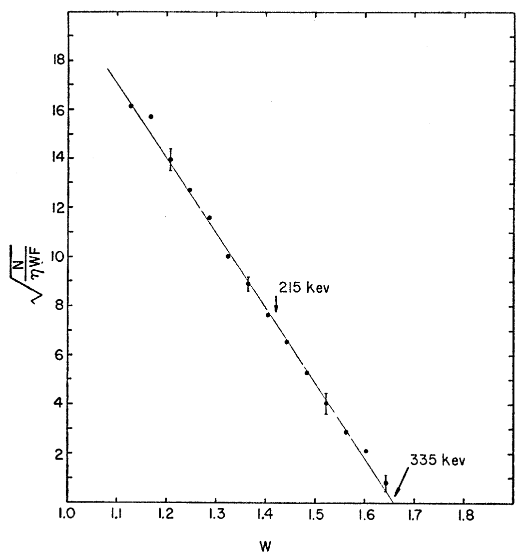

FIG. 5. Conventional Fermi plot of the beta spectrum in coincidence with the 1.29-Mev gamma ray.

Shapiro[4] the relative intensity of the 0.335-Mev beta group is ~1%. Hypothetical Fermi plots with admixtures of a 0.01 and 0.1% 0.21-Mev beta group and a 1% 0.335-Mev beta group were constructed. Comparisons were made between the experimental and hypothetical Fermi plots. This comparison and the fact that no indication of a gamma ray of about 0.12 Mev was seen in the gamma spectrum makes an estimate of the upper limit of the relative intensity of a gamma transition from the 1.42-Mev level to the 1.29-Mev level of 0.05% seem reasonable.

CONCLUSIONS

The gamma-ray studies of the present work generally confirmed the results of Gill, Mandeville, and Shapiro.[4]

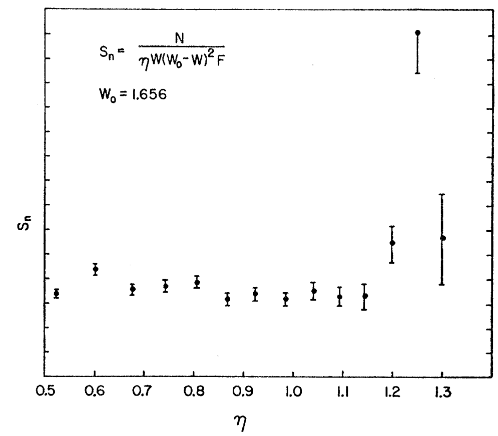

FIG. 6. Experimental shape factor for the beta spectrum in coincidence with the 1.29-Mev gamma ray.

All of the observed gammas in Cd^{115m} except the low intensity one at 1.14 Mev can be fitted into the level scheme reported by the latter group. The gamma measurements allow an upper limit of 2.5%, relative to the 0.935-Mev gamma ray, to be set on the intensity of a 0.12-Mev gamma.

The spectral character of the 0.687-Mev beta group in coincidence with the 0.935-Mev gamma ray is consistent with a spin change of 2 and a change of parity. The spin and parity, 11/2−, of Cd^{115m} appear to be reasonably well established.[2] Therefore, the assignment 7/2+, made on the basis of a γ-γ angular correlation experiment by Gill *et al.*[4] for the 0.935-Mev level in In^{115}, is probably the best choice.

The experimental shape factor, essentially a constant with respect to momentum, obtained for the beta group in coincidence with the 1.29-Mev gamma ray, and the $\log f_0 t$ value of 8.8, indicates only that the spin change is either *0* or *1*. This result does not confirm, but is consistent with the assignment of 11/2+ made by Gill *et al.*[4] for the 1.29-Mev level. Assuming that the relative intensity of the 0.687-Mev beta group is 2%, the 1.29-Mev gamma-beta coincidence results also allow an upper limit of ~0.05% to be set on the relative intensity of the transition from the 1.42-Mev level to the 1.29-Mev level.

ACKNOWLEDGMENTS

We would like to thank Mr. J. I. Rhode for his assistance in various phases of the instrumentation. The advice of Dr. E. Bleuler has been very helpful. One of the authors (WGS) would like to thank Dr. F. K. McGowan and Dr. P. H. Stelson, Oak Ridge National Laboratory, for several illuminating discussions on the improvement of resolution in scintillation spectrometry.