Nuclear Energy States of In^{115}†*

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The gamma rays of Cd^{115} and Cd^{115m} have been investigated by means of scintillation counting and coincidence methods. The K-shell conversion coefficient of the 34-keV gamma ray is measured to be 3.43 ± 0.12, suggesting the transition to be $E1$ in character and that the 858-keV level in the nucleus of In^{115} has positive parity. The gamma rays at 635, 650, and 890 keV which have been reported in the decay of Cd^{115m} are shown to emanate from Ag^{110m}, present as an impurity.

INTRODUCTION

THE energy levels of In^{115} have been studied in the course of a series of investigations.[1–15] A convenient means of excitation of these levels is by way of beta decay of Cd^{115} (2.3 days) and Cd^{115m} (43 days). Early measurements[6] showed the presence of gamma rays at 33, 230, 260, 263, 335, 490, and 523 keV, decaying with the 2.3-day activity. The same studies[6] indicated the presence of gamma rays at 485, 935, and 1290 keV in the decay of the 43-day activity. Later measurements[8] revealed the presence of a gamma ray at 1140 keV in the decay of Cd^{115m}. More recently,[10,13] the presence of radiation at 1420 keV with small intensity has been reported to be associated with the 43-day period, and soft quanta at 130, 162, and 292 keV have been detected.[10] All these data will be summarized in a disintegration scheme to be given subsequently.

THE MEASUREMENTS: Cd^{115}

The present investigation of Cd^{115} concerned itself in large degree with the nature of the 33-keV transition occurring in the decay of the 2.3-day activity. This gamma ray had not been previously detected[6] in the direct sense; that is, its photopeak had not been resolved from the photopeak of the x rays of indium. However, its presence was clearly inferred[6] from the energy difference of the gamma rays at 490 and 523 keV. The spectrum of single counts in the x-ray region is displayed in Fig. 1, where the observed shape is unfolded to indicate a contribution at 34 keV. The spectrum of quanta coincident with the 490-keV gamma ray is shown in Fig. 2. The ratio of the area under the x-ray peak to the area under the gamma-ray peak at 34 keV is taken to be a measure of the K-shell conversion coefficient of the gamma ray. After due correction for fluorescence yield and the presence of graphite absorbers introduced to prevent entry into the detectors of beta rays, the ratio gives a value for α_K of 4.80 ± 0.17. The energy calibration of these measurements actually showed the energy of the "33 keV" gamma ray to be somewhat greater, 34 keV, which exceeds the K-absorption edge of iodine. A recent measurement[12] of this energy has yielded a value of 34.5–35 keV. Therefore, immersed in the noise

TABLE I. Values of α_K for indium at 34 keV suggested by theoretical computation.

Reference	α_K ($E1$, extrapolated)	α_K ($M1$, extrapolated)
17		8.0
18	3.1	12.0
19	2.9	9.0

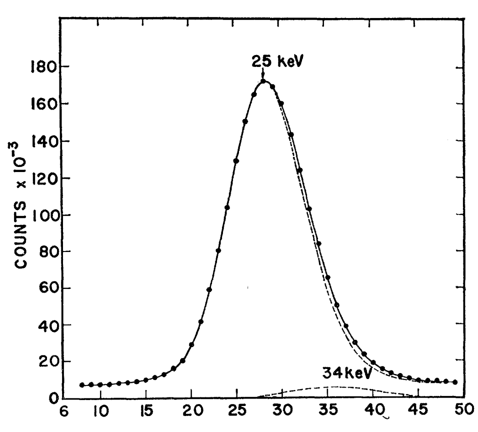

FIG. 1. Spectrum of single counts in the x-ray region. The K line of indium is present with a much smaller contribution at 34 keV.

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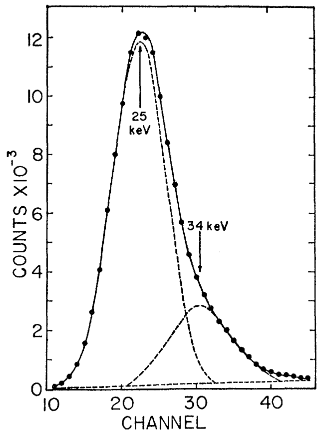

FIG. 2. Gamma-gamma and gamma-(x-ray) coincidences in the 34–490-keV cascade. The K-shell conversion coefficient of the 34-keV gamma ray is calculated from these data.

of the detecting system, is an escape peak of area 40% of that of the full energy peak at 34 keV. When the area assigned to the gamma ray is accordingly corrected[16] for the presence of the escape peak, the K-shell conversion coefficient becomes 3.43±0.12. This experimentally determined value of α_K is to be compared with those determined from theoretical calculations.[17–19] In no case has α_K for indium at 34 keV actually been calculated. However, in three cases, the theoretically computed values have been visually extrapolated. These results are summarized in Table I. Threshold values of the conversion coefficients have recently been calculated.[20] In the case of indium, the threshold evaluations occur at 27.928 keV. The computations indicate α_K ($E1$) to be 5.20 and α_K ($M1$) to be 9.0. These values are not inconsistent with the presently reported experimentally determined value of 3.43±0.12, if the 34-keV transition is taken to be $E1$ in character. The presence of an $E1$ transition in the de-excitation of indium (115) requires a state of positive parity among the nuclear energy levels of In^{115}. Previous studies show the 858-keV level of In^{115} to be populated by a beta spectrum of log ft value 6.5, not inconsistent with an allowed unfavored l-forbidden transition ($\Delta I=1$, No!, $\Delta l=2$). A spin value of $\frac{3}{2}+$, orbital $d_{3/2}$, is predicted for the 858-keV level.

The conversion coefficient of the 34-keV gamma ray of Cd^{115} has been measured[12] previously as 7.6±0.8. However, a visual examination of the reported[12] coincidence curve (Fig. 3, Ref. 12) will disclose that the experimentally observed curve, which shows the x-ray and the 34-keV gamma ray only partially separated, has been incorrectly resolved into two components. For example, the ordinate of the point of intersection of the two resolved peaks does not equal the ordinate of the experimentally observed curve when doubled. Accordingly, the data have been reanalyzed by the present authors to yield a conversion coefficient of 5.81±0.68.

The detectors utilized in the measurement of α_K were crystals of NaI(Tl), $1\frac{1}{2}$ in. in diameter, 1 in.-thick, and $1\frac{1}{2}$ in. in diameter, 0.6 cm thick, each mounted upon an RCA-6342A photomultiplier tube. Energy "gates" in the slow-fast coincidence experiment were provided by the $1\frac{1}{2}$-in.×1-in. crystal. The angular separation of the counters was 180 deg, with a source-to-crystals distance of 1 cm. This approximate 4π geometry was employed to reduce the effects of angular dependence of the coincidence rate. Graphite absorbers, of thickness 0.83 cm, were used to shield the detectors from the beta spectrum. The correction factor for relative absorption in graphite of 25-keV x rays and 34-keV gamma rays was experimentally determined for the particular geometry employed by measuring the attenuation of x radiations in graphite at 22.5 keV (Cd^{109}), 24.9 keV (Cd^{115}), 30.6 keV (Ba^{133}), 32.2 keV (Cs^{137}), and 36.5 keV (Ce^{141}). The size and spatial distribution of the sources used in these attenuation measurements were matched to those of the sources of the measurements of α_K. This experimentally determined correction factor, obtained by taking into account effective absorber thickness, scattering, etc., is precise. Two different coincidence-analyzer systems were used in the investigation. One system included a Nuclear Data 512-channel analyzer in conjunction with a slow-fast coincidence system assembled at this laboratory, the other a TMC

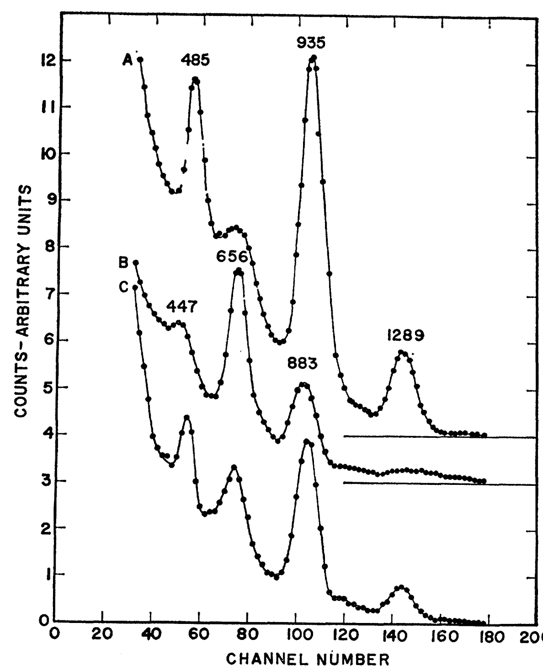

FIG. 3. Spectra of single counts of gamma rays of Cd^{115m}. Curve A: gamma rays of chemically purified Cd^{115m}. Curve B: spectrum of gamma rays of Ag^{110m} chemically separated from Cd^{115m}. Curve C: gamma rays of aged impure source of Cd^{115m}.

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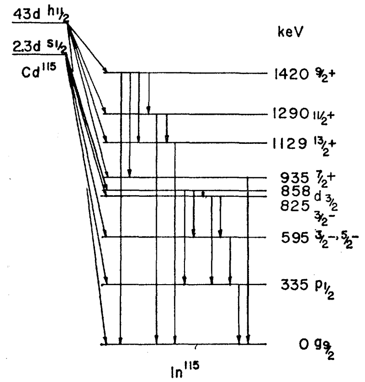

FIG. 4. Nuclear level structure of In^{115} as revealed by beta decay of the isomers of Cd^{115}. This decay scheme combines present measurements with those of some of the quoted references.

400-channel analyzer and a Sturrup slow-fast coincidence package. The coincidence resolving times of the two systems were respectively 5×10^{-7} sec and 0.5×10^{-7} sec. The slow-fast coincidence systems were gated on the lower side of the (490-523) keV composite peak of the spectrum of single counts, and the coincident x rays and gamma rays were detected in the thinner crystal. With the system secondly described, it is possible to simultaneously obtain the coincidence spectrum and its corresponding chance coincidence spectrum. The Nuclear Data system does not have this capability, and so correction for decay of the source was required. All results obtained with either system lay within the probable error of the presently quoted value of α_K.

Before departing discussion of measurements relating to the decay of Cd^{115}, it should be remarked that additional coincidence studies were performed which confirmed the presence of the previously reported[6] 230–260-keV and 263–260-keV gamma-ray cascades.

THE MEASUREMENTS: Cd^{115m}

Over a lengthy period of decay, the properties of Cd^{115m} have been observed at intervals. In the early stages of decay, the radiations of Cd^{115m} are dominant. However, after several half-periods, unless chemical purification has been effective, the radiations of Ag^{110m} become apparent. In Fig. 3 are shown pulse-height spectra of Cd^{115m}, of Cd^{115m} after several half-periods of decay, and of the silver fraction separated from Cd^{115m}. Of recent date gamma rays of quantum energies 635, 650, and 890 keV have been reported[11] in the decay of Cd^{115m}. These radiations are considered not to be associated with Cd^{115m}, and are assigned to Ag^{110m}, present as an impurity.

CONCLUSION

The presently known data concerning In^{115} are summarized in Fig. 4. Excited states at 335, 595, 825, 858, 935, 1129, 1290, and 1420 keV are indicated. Evidence has been obtained which shows at least two levels at or near 1420 keV.[9,10,13] Apparently not revealed by beta decay is a level in In^{115} at 1.04 ± 0.02 MeV,[14] excited by x-ray bombardment. A recent analysis[15] of the results of neutron scattering experiments favors spin and parity $\frac{3}{2}$- for the 595-keV state. However, this conclusion is based upon the assumption that the metastable state is populated by de-excitation of states of negative parity only. The results of the measurements presently reported thus render this analysis[15] inexact.