LEVELS IN ^{110}Cd POPULATED IN THE DECAY
OF 69 min ^{110g}In

DEMETRIOS G. SARANTITES

Chemistry Department, Washington University, St. Louis, Missouri 63130 †

and

NOAH R. JOHNSON and H. W. BOYD †††

Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830 ††

Abstract: The level structure of ^{110}Cd has been investigated from the decay of 69 min ^{110g}In. Singles γ-ray spectra were taken with a large-volume, high-resolution Ge(Li) detector. Extensive γ–γ coincidence measurements were made with both NaI–NaI and NaI–Ge(Li) arrangements. From these data it was concluded that levels at 657.5, 1475.2, 1540.9, 1731.5, 1783.3, 1809.0, 2078.8, 2355.5, 2463.1, 2786.5, 2868.3, 2974.1, 3077.9, 3101.4, 3193.8, 3313.3, 3402, 3451.1, 3464.3, 3474, 3596, 3701 and 3770 keV in ^{110}Cd are populated in the decay of 69 min ^{110g}In. From log *ft* values determined in this work and from γ-ray intensity information, limits have been placed for the J^π values of many levels. The half-life of ^{110g}In has been measured and found to be 69.1 ± 0.5 min.

E | RADIOACTIVITY ^{110g}In; measured $T_{\frac{1}{2}}$, E_γ, I_γ, $\gamma\gamma$-coin; deduced log *ft*. ^{110}Cd deduced levels J, π. NaI(Tl), Ge(Li) detectors.

1. Introduction

The decay of 69 min ^{110g}In has been studied in recent years by Katoh *et al.* [1]) and Nainan *et al.* [2]) by means of NaI(Tl) scintillation γ-ray detectors. The last mentioned authors reported levels at 656, 1474, 1541, 1790, 1910, 2060, 2820, 3110, 3400 and 3650 keV populated in the decay of ^{110g}In. The low angular momentum states in ^{110}Cd populated in the decay of 25 sec ^{110g}Ag have been investigated recently by Kelley *et al.* [3]) who found that ^{110}Cd levels at 657.8, 1473.4, 1475.6 and 1783.5 keV are populated in this decay. These authors present arguments for the assignment of the spin-parity of the 1473.4 keV state as 0^+. The high angular momentum states in ^{110}Cd have been investigated recently from the decay $^{4-9}$) of the 6^+, 253 d ^{110m}Ag, and from the decay [1,10,11]) of the 7^+ 4.9 h ^{110m}In. Also, levels in ^{110}Cd have been investigated in a number of nuclear reaction studies. In particular, we mention the (d, d') study of Kim and Cohen [12]), who proposed levels at 650, 1180, 1470, 1540,

††† Permanent Address: West Georgia College, Carrollton, Georgia.

2090, 2230, 2510, 2580, 2690 and 2830 keV; the (p, p') work of Cookson and Darcey [13]) who propose levels at 657(2$^+$), 1476(2$^+$), 1544(4$^+$), 1740, 1790, 1820 and 2083(3$^-$) keV; the (p, p') work of Koike *et al.* [14]) who assigned levels at 660(2$^+$), 1476(2$^+$), 1544(4$^+$), 1740, 1790, 1820, 2080(3$^-$), 2163(3$^+$), 2220(4$^+$), 2490(6$^+$) and 2920(5$^+$); and the Coulomb excitation (^{16}O, ^{16}O'γ) work of McGowan *et al.* [15]) who reported levels at 656(2$^+$), 1473(2$^+$), 1541(4$^+$) and 2051(3$^-$) keV.

Although the low-energy level structure of ^{110}Cd may appear to be well studied, as indicated from the above summary, there still remained a number of points that needed clarification. For example, the position of a 0$^+$ low-lying level which is often attributed to a two-phonon excitation was not clear for ^{110}Cd. Kim and Cohen [12]) suggested that the 0$^+$ level may be the 1180 keV level that they observed from the (d, d') excitation of ^{110}Cd, strictly by analogy with such levels in ^{112}Cd and ^{114}Cd. Nainan *et al.* [2]) in their study of the decay of ^{110g}In found no evidence for such a level. However, while we were investigating ^{110g}In, Kelley *et al.* [3]) studied the decay of ^{110g}Ag and found strong evidence for a 0$^+$ level at 1473.4 keV which is only 2 keV below the known 2$^+$ level. Since ^{110g}In probably has a spin of 2$^+$, it seemed possible that this 0$^+$ state may be populated in gamma-ray cascades from high-lying ^{110}Cd states of low spins and, therefore, a high-resolution study could provide additional data on its properties. Another point that needed clarification is the position of the 3$^-$ octupole state as well as the locations of other negative parity states. Finally, any collective character in the states in ^{110}Cd should be reflected in the positon branching to these levels.

This investigation was undertaken because it was thought that with the increased sensitivity of the Ge(Li) detectors, information could be obtained on some of the above mentioned points as well as on completely new aspects of the ^{110}Cd level scheme. Indeed, our experimental measurements have led to a proposed decay scheme which includes many levels that have not been reported previously and which, apart from the lowest levels (below $\approx$ 2100 keV), shows virtually no resemblance to the scheme reported earlier [2]).

2. Experimental procedures

2.1. PREPARATION OF THE ^{110g}In SAMPLES

For the singles measurements of the γ-ray energies and intensities, sources of the 4.0 h ^{110}Sn were prepared at the Washington University cyclotron by the reaction ^{108}Cd(^{4}He, 2n) with 26 MeV ^{4}He ions on natural 20 mg/cm^2 Cd foils. The decay of the 4.0 h ^{110}Sn is followed by the emission of only one γ-ray at 280 keV which does not interfere with the γ-rays from ^{110g}In. Other tin activities present in these samples were ^{113}Sn (γ-rays at 255 and 393 keV) and ^{117m}Sn (γ-rays at 158 and 159 keV). All these γ-rays are of low energy and do not interfere with the determination of the radiations from ^{110g}In above 400 keV. The ^{110}Sn samples were purified according to the following radiochemical procedure. After the bombardment, about

four hours were allowed for decay of the 18 min ^{109}Sn and 35 min ^{111}Sn, and then the Cd target foils were dissolved in a small amount of conc. HNO_3 containing In^{III} and Sn^{+2} carriers. The HNO_3 was destroyed by boiling to near dryness in the presence of HCl. Tin was separated first as SnS_2 and then as tetramethylammonium chlorostannate. Further purification was achieved by extracting In^{III} into methyl-isobutyl ketone from a solution of 0.3 M H_2SO_4, 0.4 M NaCl and 0.6 M KI containing 2.0 mg of iodide ion per ml. Finally, Sn was precipitated as SnS_2 and mounted for counting. No contaminating ^{110m}In activity could be detected in these samples.

For the NaI(Tl)–Ge(Li) coincidence experiments, sufficiently active samples of ^{110}Sn could not be prepared easily by the ^{110}Cd(^{4}He, 2n) reaction on natural Cd. For this purpose we used samples of ^{110g}In produced by the reaction ^{107}Ag(^{4}He, n) with 14 MeV ^{4}He ions on natural Ag foils. Following bombardment, the Ag target foils were dissolved in conc. HNO_3 containing In^{III} carriers. The indium was purified by precipitating $In(OH)_3$, which was dissolved in 48 % HBr solution and extracted into isopropylether. In^{III} was then extracted back into 6 M HCl and $In(OH)_3$ was precipated and mounted for counting.

Additional sources for both singles and coincidence measurements were prepared by bombarding CdO target material enriched in mass 110 with 55 MeV ^{4}He ions in the Oak Ridge Isochronous Cyclotron to give the reaction ^{110}Cd(^{4}He, 4n)^{110}Sn. Chemical purification was effected by dissolving the target in 1 M HF and eluting the tin from a column of cation exchange resin with additional 1 M HF. These sources were of very high purity with the only interfering activity being a very small trace of ^{113}Sn.

2.2. DETECTION EQUIPMENT AND METHODS OF COUNTING

For γ-ray counting both NaI(Tl) and Ge(Li) detectors were used. The NaI(Tl) detectors were integrally mounted 7.6 cm × 7.6 cm crystals. The Ge(Li) detectors used had active volumes of 20 and 30 cm^3 with a system resolution (FWHM) of 2.8 and 4.0 keV respectively, for the 1332 keV γ-ray from a ^{60}Co source.

In the γ–γ coincidence measurements two NaI(Tl) detectors were employed in some early experiments, and a NaI(Tl) detector and a 20 cm^3 Ge(Li) detector were employed in later experiments. The properties of the Ge(Li) detectors and the two parameter pulse-height analysis systems used have been described elsewhere [16-18]. The coincidence resolving times employed were $\approx$ 100 nsec and the random coincidence rate was less than 5 % of the total coincidence rate. In view of this fact, the random events were not subtracted from the spectra used in the illustrations. However, in the coincidence experiments where the random coincidence correction seemed necessary, it was performed by a computer program.

3. Results and construction of the decay scheme

We have remeasured the half-life of ^{110g}In by following the decay of the γ-ray activity (γ-rays with energy greater than 2.0 MeV) and in separate experiments the
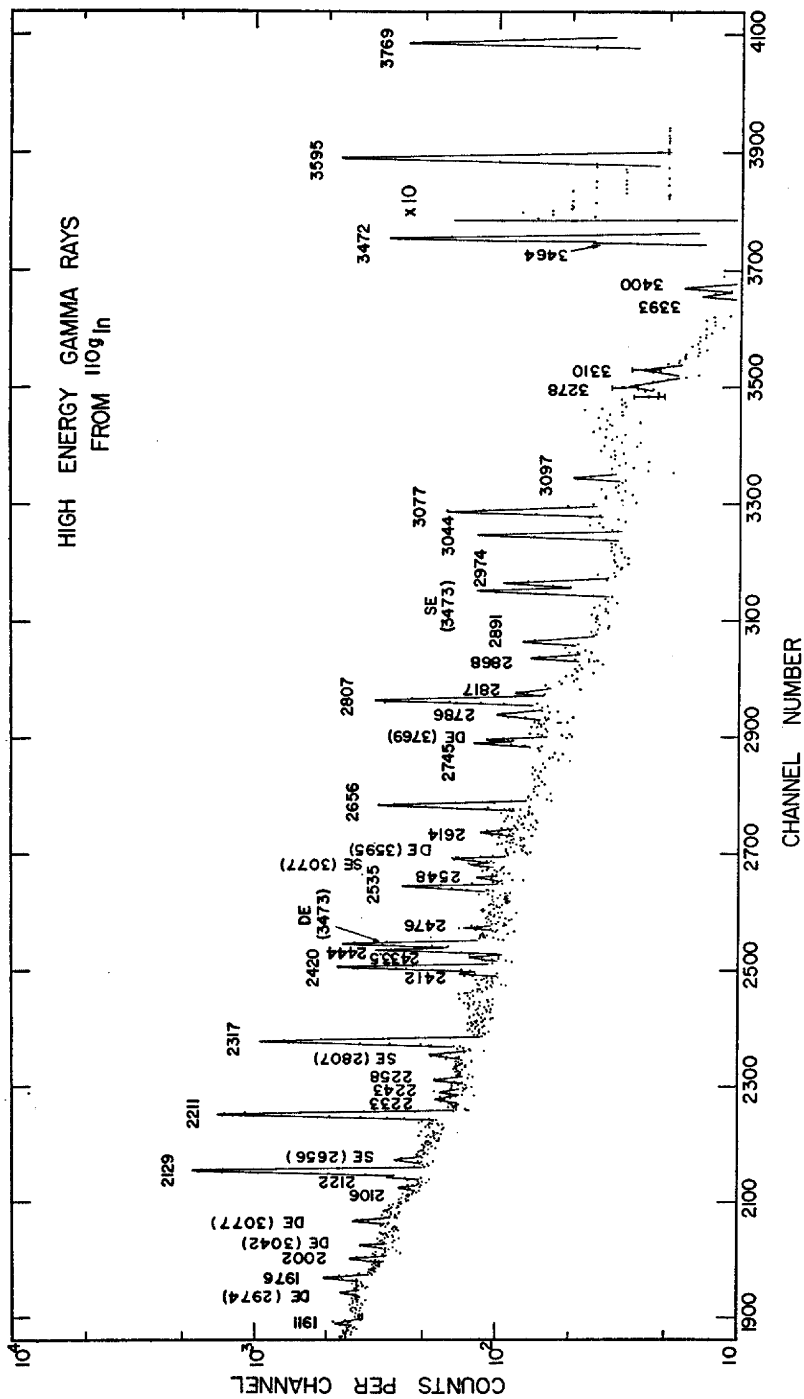
Fig. 2. Singles γ-ray spectrum from ^{110g}In decay obtained with a 20 cm³ Ge(Li) detector. The γ-rays in the energy range 1900–3800 keV are displayed.

and was omitted. The high-energy portion of the ^{110g}In γ-ray spectrum is shown in fig. 2. The energies and relative intensities of the γ-rays listed in table 1 were determined from the peak centroids and areas as described elsewhere [19]).

TABLE 2

Summary of the observed γ–γ coincidence relationships from ^{110g}In decay

Fig. no.	γ-rays in the gate (keV)	γ-rays in the coincidence spectrum [a]) (keV)
3a	511	658, 817, 1125, 1421
3b, 4a	658	511, 604, 681, 817, 884, 958, 1000, 1023, 1073, 1125, 1236, 1421, 1505, 1618, 1698, 1976, 2002, 2129, 2211, 2317, 2420, 2444, 2535, 2656, 2745, 2807 [e])
6a	817	1236, 1618, 2002
6b	883, 958 [b])	1300, 1347, 1530 [c]), 1603 [c]), 1630 [c])
6c	958, 1000, 1023,	1421, 1476, 1698, 1725
5a	1048 [b]), 1074 [b]), 1085 [b]), 1125, 1152 [b])	511, 658, 1000, 1125, 1476
5b	1236, 1347 [b])	603, 658, 817, 1421, 1505
7a	1236	1421
7b	1347, 1388 [d])	1421
7c	1388, 1410 [b]), 1421, 1460 [b])	1236
7d	1460 [b]), 1476, 1505 [b])	1236, 1388, [c]) 1603, 1630, 1744 [c])
5c	1603, 1618, 1630, 1635, 1654, 1667, 1698 [d])	511, 658, 817, 1125
5d	1698 [d]) 1724 [b]), 1774 [b]) 1785	658, 681, 817, 1048, 1086
5e	2002, 2106, 2129	658, 817, 1048

[a]) Only the γ-rays identified with ^{110g}In are included in this list. The γ-rays in coincidence with the underlying Compton background are not included in this list.
[b]) Weak γ-rays included in the gate.
[c]) Observed weak coincidences.
[d]) Only a small fraction of this peak is included in the gate.
[e]) Observed in the NaI–NaI coincidence data.

The γ–γ coincidence relationships were established by recording the coincidence spectra in a 100×200 channel two-parameter configuration employing two NaI(Tl) detectors, and in a 256×1024 channel two-parameter configuration employing a NaI(Tl) and a Ge(Li) detector. The coincidence relationships are summarized in table 2 and most of the important parts of the NaI-Ge coincidence spectra are display-

ed in figs. 3–7. Although the NaI–NaI coincidence spectra suffer from poor resolu-
tion, they are of good statistical quality and therefore serve as corroborative evi-
dence for the measurements with NaI–Ge, and in a few cases illustrate features not
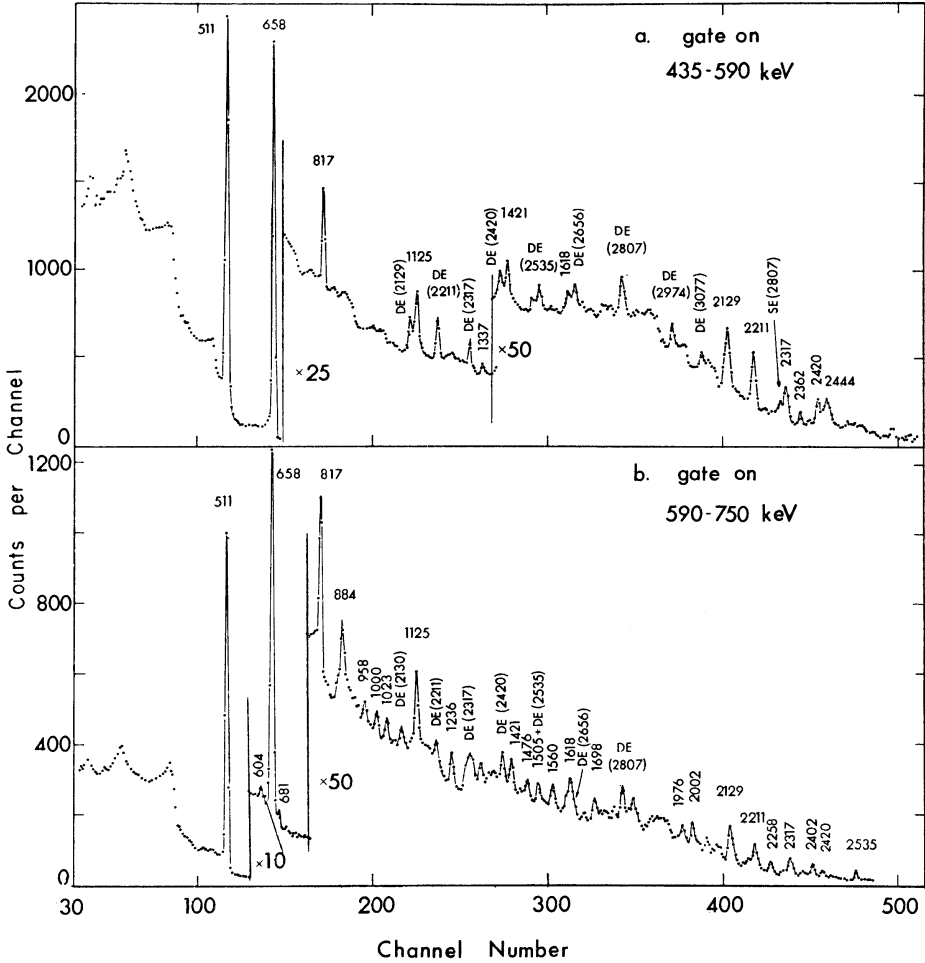prominent in the higher-resolution data.

Fig. 3. Spectra of the γ-rays from ^{110g}In decay obtained with a 30 cm^3 Ge(Li) detector in coincidence
with the indicated energy regions in the NaI(Tl) spectrum. These spectra are displayed after a
3-point smoothing.

On the basis of this evidence a decay scheme shown in fig. 8 was constructed and
arguments for the proposed scheme are given below.

3.1. DEFINITIVE LEVELS

The definitive levels are based on observed γ–γ coincidence relationships and are
further supported by energy sums.

The 657.5 keV *level.* The 657.5 keV γ-ray is by far the most intense γ-ray and certainly populates the ground state.

The 2^+, 1475.2 keV *level.* This level is well established from the ^{110m}Ag and ^{110m}In decay scheme studies [4−11]). From ^{110m}In decay [11]) the 817.4 keV γ-ray was observed
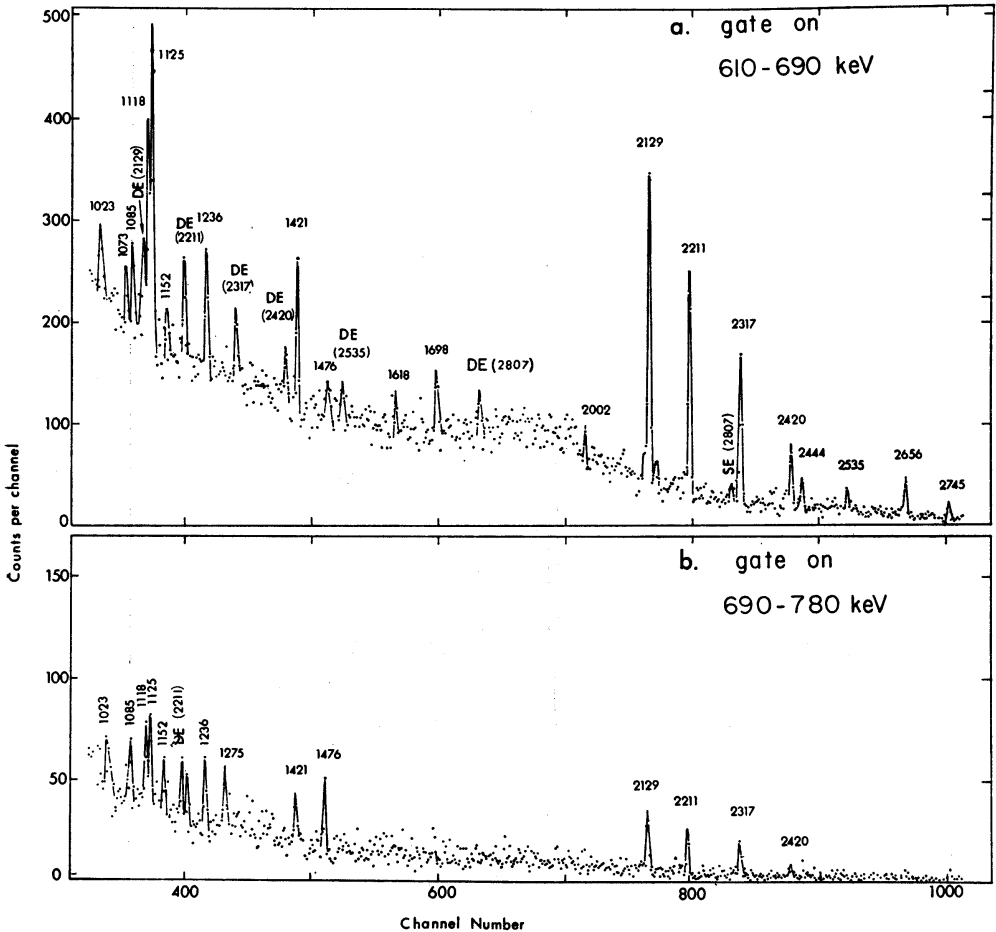

Fig. 4. Spectra of the γ-rays from ^{110g}In decay obtained with a 20 cm³ Ge(Li) detector in coincidence with the indicated regions in the NaI(Tl) spectrum. Except for a few events from the 690 keV gamma ray, the gate in fig. 4b includes only Compton events from higher-energy gamma rays. This figure is shown merely to illustrate the shape of such contribution in fig. 4a.

in coincidence with the 657.5 keV γ-ray establishing the level at 1475.2 keV with the 1475.5 keV γ-ray assigned to populate the ground state. This result is confirmed also from the decay of ^{110g}In (fig. 3b).

The 1540.9 keV *level.* The weak 883.4 keV γ-ray was observed in strong coincidence with the 657.5 keV γ-ray (fig. 3b). This level is well established from ^{110m}Ag and

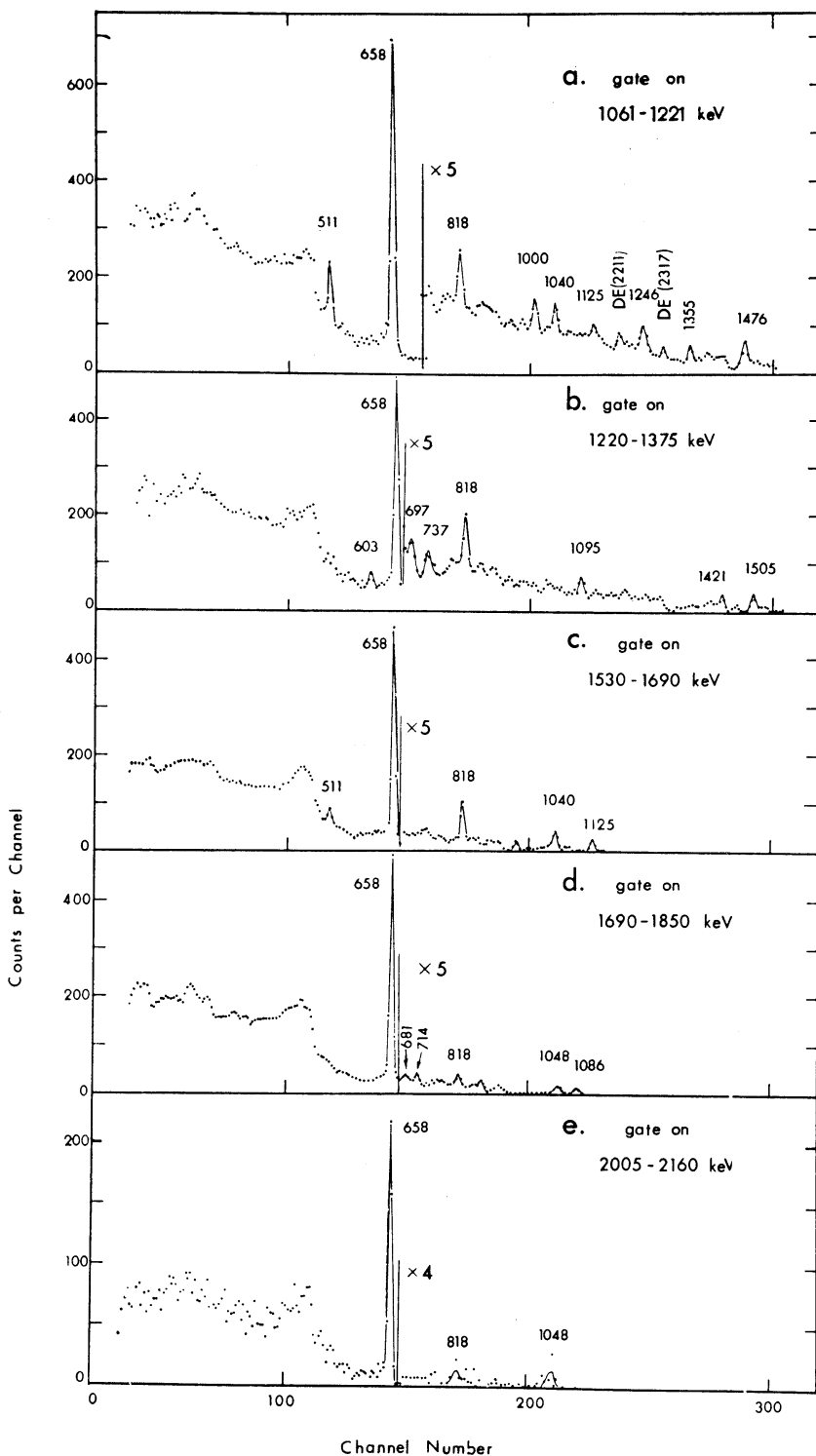Fig. 5. Spectra of the γ-rays from ^{110g}In decay obtained with a 30 cm³ Ge(Li) detector in coincidence with the indicated energy regions in the NaI(Tl) spectrum. These spectra are displayed after a 3-point smoothing.
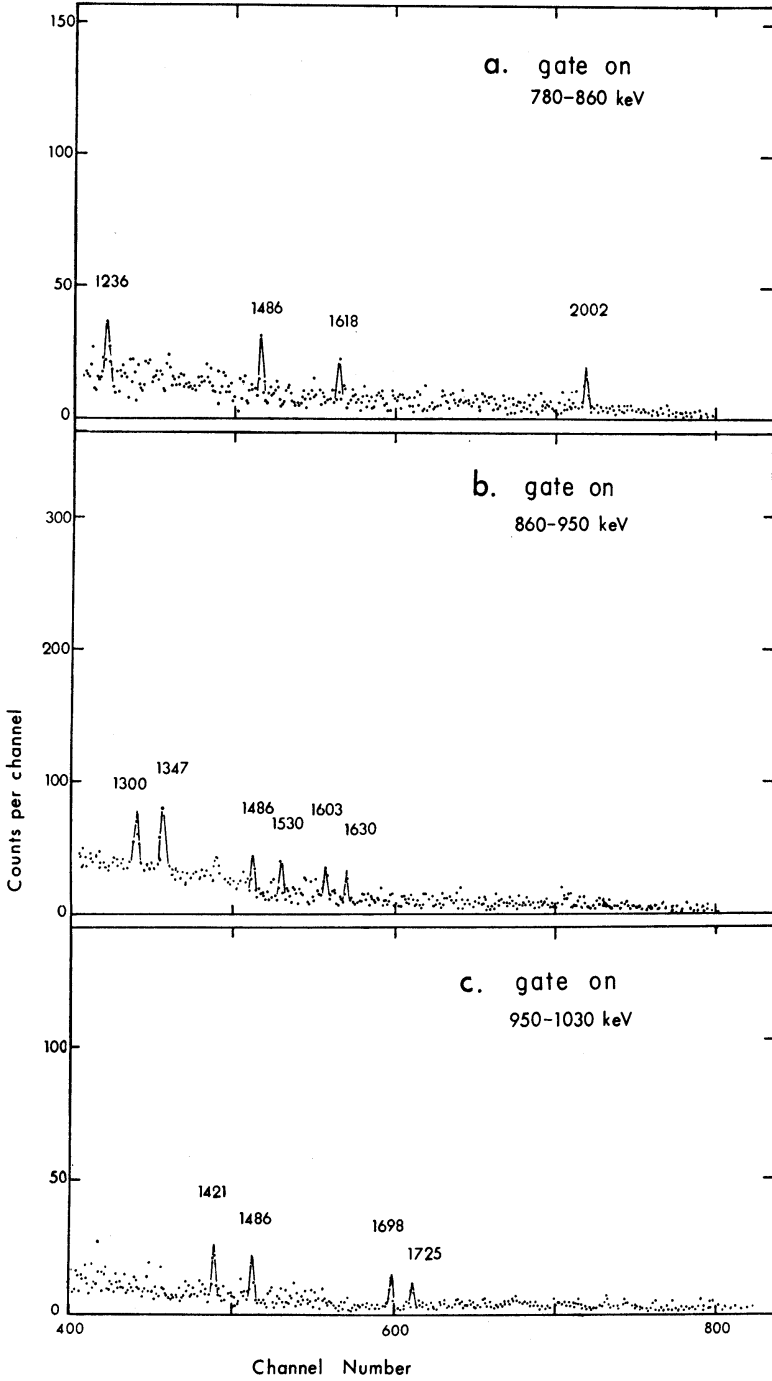
Fig. 6. Spectra of the γ-rays from ^{110g}In decay obtained with a 20 cm³ Ge(Li) detector in coincidence with the indicated regions in the NaI(Tl) spectrum.

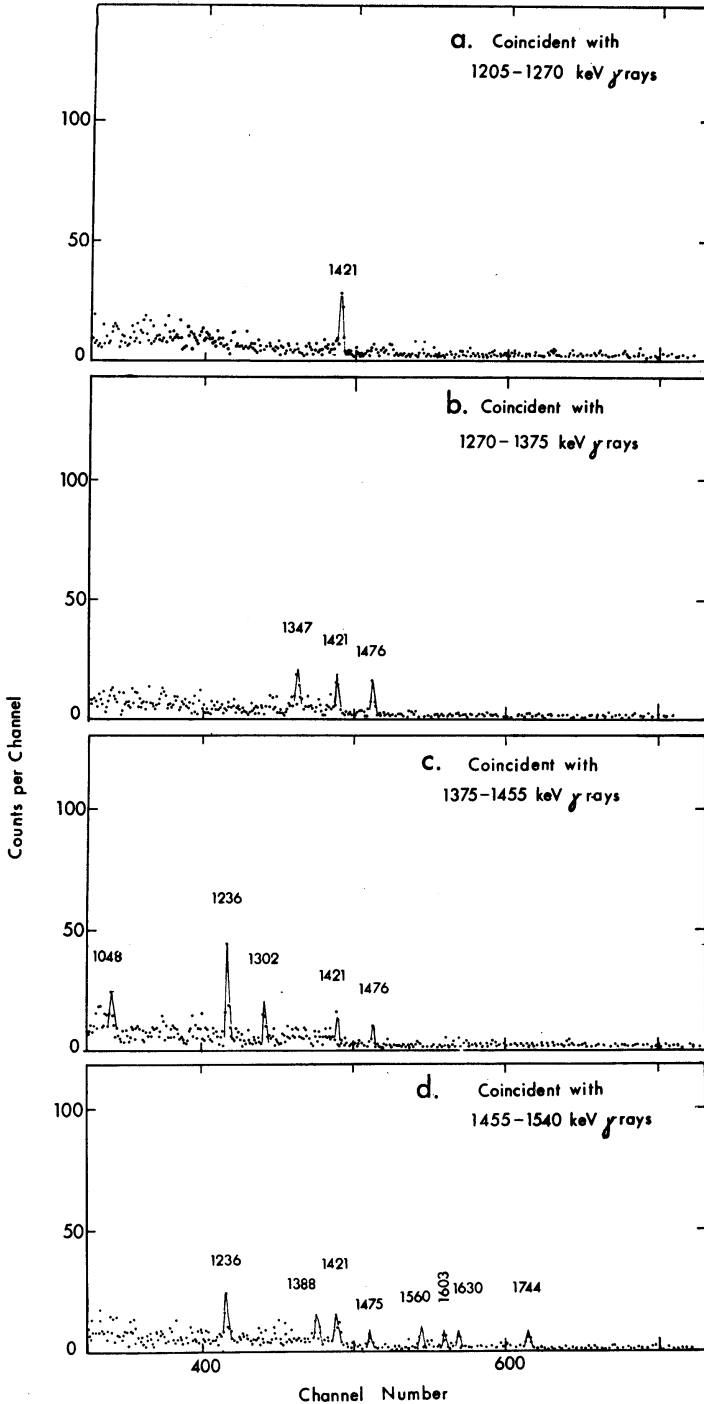Fig. 7. Spectra of the γ-rays from ^{110g}In decay obtained with a 20 cm³ Ge(Li) detector in coincidence with the indicated regions in the NaI(Tl) spectrum.
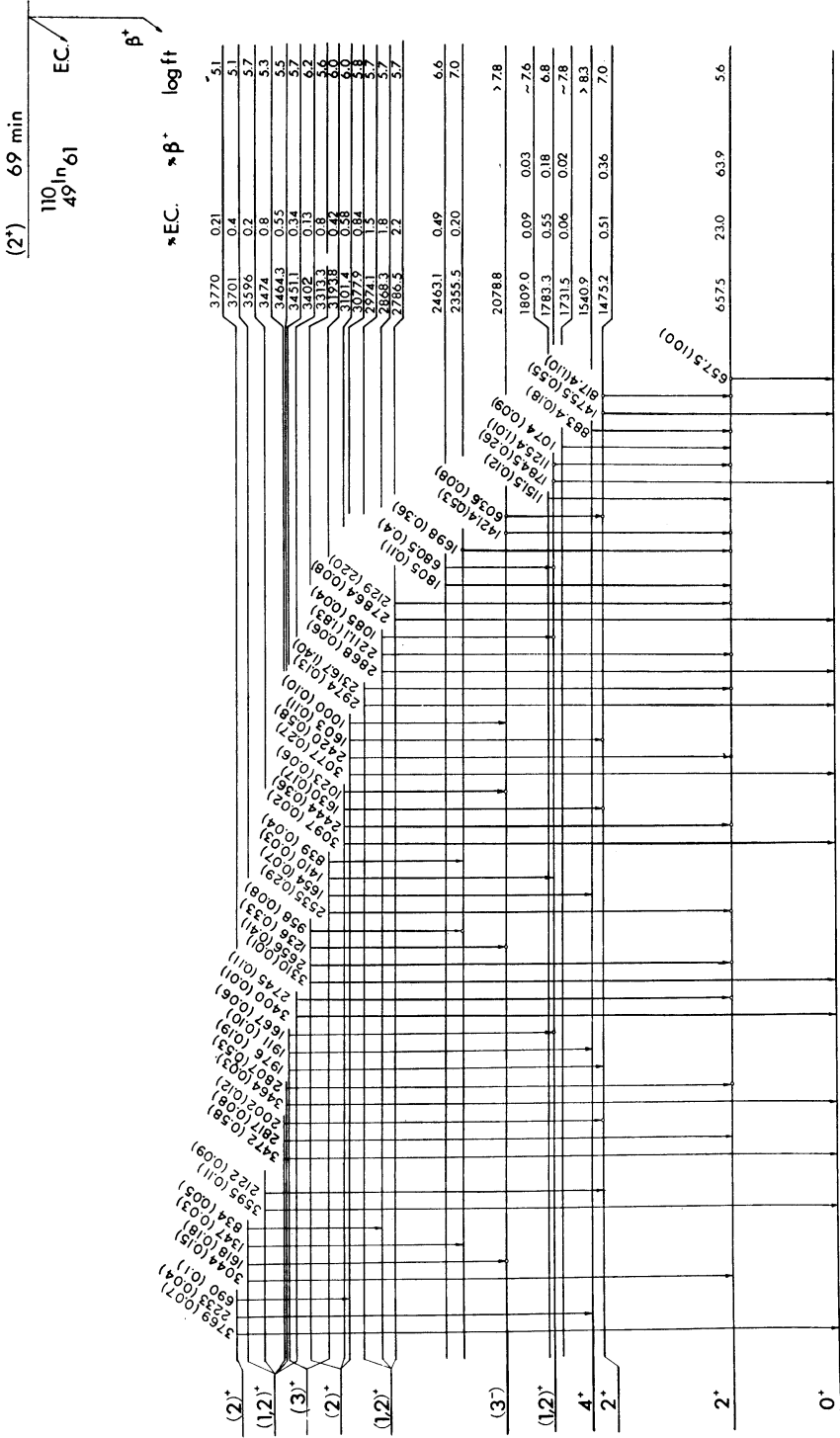
Fig. 8. Proposed decay scheme for the 69 min ^{110g}In. All energies are given in keV and the intensities of the observed γ-rays are given in parentheses relative to the 657.5 keV γ-ray taken as 100.

^{110m}In decay $^{4-11}$), and it is further confirmed by a number of transitions assigned to populate it from established levels at higher energy.

The 1783.3 keV *level.* This level was established by the observed strong coincidence of the 1125.4 keV γ-ray (fig. 3b) with the 657.5 keV γ-ray. The 1784.5 keV γ-ray was assigned to populate the ground state. These assignments are consistent with the coincidence relationships observed between the 1125.4 and 1784.5 keV γ-rays and γ-rays originating from established higher-energy levels (see fig. 8).

The 2078.8 keV *level.* The 603.6 keV γ-ray was observed in coincidence with the 657.5 and 1235.7 keV γ-rays (figs. 3b, 5b) but not with the 817.4 keV γ-ray, probably because of low efficiency and intensity. The 1421.4 keV γ-ray was seen in coincidence with the 657.5 and 1235.7 keV γ-rays (figs. 3b, 5b). This information strongly supports a level at 2078.8 keV.

The 2355.5 keV *level.* The 1698 keV γ-ray was observed in coincidence with the 657.5 keV γ-ray (fig. 3b). Also, this γ-ray was observed in coincidence when the NaI detector was gating on the 950–1030 keV region of the spectrum (fig. 6c). This signifies a coincidence with the 958, 1000 or 1023 keV γ-rays. Since the 1000 and 1023 keV γ-rays are assigned elsewhere in the scheme (see fig. 8) it is reasonable to assume that the 958 and 1698 keV γ-rays are in coincidence. Furthermore, the 958 keV γ-ray is substantially weaker than the 1698 keV γ-ray and is therefore assumed to populate the level deexcited by the 1698 keV γ-ray. Hence, we assign the 958 keV γ-ray as the cascading transition from a level at 3313 keV.

The 2463.1 keV *level.* The 680.5 keV γ-ray was seen in coincidence with the 1690–1850 keV region of the NaI(Tl) detector (fig. 5d). Since the 1784.5 keV γ-ray is the most intense of the γ-rays in the gated region (with the exception of the 1699 keV γ-ray assigned elsewhere in the scheme) it is more likely that it is in direct coincidence with the 680.5 keV γ-ray. The 1805 keV γ-ray was assigned to populate the 657.5 keV level on the basis of good energy agreement.

The 2786.5, 2868.3, 2974.1, 3077.9, 3101.4, 3313.3 *and* 3402 keV *levels.* These levels are established on the basis of observed coincidence relationships of cascading transitions with the 657.5 keV γ-ray and on the fact that the data indicate a ground state transition at each of these energies.

The 3193.8 keV *level.* This level is evidenced by the observed coincidence of the 2535 keV γ-ray with the 657.5 keV γ-ray and it is further supported by the observed γ-rays at 839, 1410 and 1654 keV assigned to populate the levels at 1540.9, 1783.3 and 2355.5 keV on the basis of good energy agreement.

The 3451.1 keV *level.* This level is based on observed energy sums with the 1667, 1911 and 1976 keV γ-rays assigned as cascading transitions from this level.

The 3464.3 keV *level.* This level is based (i) on an observed coincidence of the double escape peak from the 2807 keV γ-ray with the 657.5 keV γ-ray in the NaI-Ge ex-

periments (figs. 3b and 4a) and (ii) on an observed coincidence of a 2802 keV γ-ray with the 657.5 keV γ-ray in the NaI–NaI experiments. This level is further supported by the 3464 keV γ-ray assigned as a ground state transition.

The 3474 keV *level.* This level is assigned on the basis of an observed coincidence relationship between the 2002 keV γ-ray and the 817.4 keV γ-ray (fig. 6a). It is further supported by the presence of γ-rays at 3472 and 2817 keV assigned to populate the ground and 657.5 keV states, respectively.

The 3701 keV *level.* The 1618 keV γ-ray was observed in weak coincidence with the the NaI-gate covering the 780–860 keV region and in strong coincidence with the 657.5 keV γ-ray (figs. 6a and 3b). This information is consistent with the assignment of the 1618 keV γ-ray to populate the 2078.8 keV level. The γ-rays at 834, 1347 and 3044 were assigned to populate the levels at 2868.3, 2355.5 and 657.5 keV, respectively, on the basis of energy sums. The 1347 keV gamma-ray assignment is also substantiated by the coincidence data.

The 3596 *and* 3770 keV *levels.* These levels are based on observed energy sums and on the fact that the 3595 and 3769 keV γ-rays are of sufficiently high energy that any assignment other than the ground state would require levels exceeding the available decay energy (Q_{EC} = 3930 keV).

3.2. TENTATIVE LEVELS

$A(0^+)$ *level at* 1473.4 keV. From the intensities given by Brahmavar *et al.* [9]) for the 818.00 and 1475.73 keV γ-rays from the 6^+ ^{110m}Ag decay we calculate the value 1.73±0.10 for the ratio $I(818)/I(1476)$. However, in the decay of ^{110}Ag, Kelley *et al.*[3]) obtained the value of 8.1±1.8 for the intensity ratio of a slightly broadened peak at 815.6 keV and a peak at 1473.4 keV. They attributed this to the fact that in the decay of ^{110}Ag (1^+) the primary population is to a (0^+) level at 1473.4 keV. From the present work we obtain the value of 2.00±0.14 for the ratio $I(817.4)/I(1475.5)$. This value is slightly higher than that from the ^{110m}Ag decay and may suggest a weak population of the (0^+) state at 1473.4 keV. However, within the assigned error limits these values nearly overlap and this does not allow us to conclude with certainty the population of this (0^+) level from the ^{110g}In decay.

The 1731.5 *and* 1809.0 keV *levels.* Evidence for these two levels is derived from the coincidence relationship between the γ-rays at 1074 and 1151.5 keV and the 657.5 keV transition, and they are tentatively identified with the levels at 1740 and 1820 keV observed in the (p, p′) study of Cookson and Darcey [13]).

4. Assignment of J^π values and discussion

The total angular momentum and parity J^π for the even nucleus ^{110}Cd are certainly 0^+. The 69 min ^{110g}In decays strongly (log ft = 5.6) to the 2^+, 657.5 keV

level in ^{110}Cd but not to the 0^+ ground state or the 4^+ state at 1540.9 keV. This probably indicates a J^π value of 2^+ for ^{110g}In. The log ft values given in fig. 8 are based on the fraction of β-decay to the levels in ^{110}Cd obtained from γ-intensity balances using the intensities from this work. For this purpose the value of 3930 keV for Q_{EC} was used, based on the value of 2.25 MeV for E_{β^+} to the 657.5 keV level given by Bleuler *et al.* [20]). The log ft values were calculated using Moszkowski's nomographs [21]) in an expanded form [22]). As all the transitions observed had energies greater than 600 keV, corrections for internal conversion were not applied. The percentage electron capture and positon decay to each level were calculated from the measured β-feeding and the E.C./β^+ ratios were calculated from ref. [22]), p. 575.

The low-lying states at 657.5(2^+), 1475.2(2^+) and 1540.0(4^+) keV have been studied by means of Coulomb excitation by McGowan *et al.* [15]) and by Milner *et al.* [23]). These authors have determined B(E2) values for the $4_1^+ \rightarrow 2_1^+$, $2_2^+ \rightarrow 2_1^+$ and $2_1^+ \rightarrow 0^+$ transitions and have compared their results with the predictions of the asymmetric rotor model and the vibrational model. Milner *et al.* [23]) have determined the ratio $B(E2, 2_2^+ \rightarrow 2_1^+)/B(E2, 2_1^+ \rightarrow 0^+)$ to be 1.08 ± 0.29 using a branching ratio of 1.83 ± 0.13 for $I(818)/I(1475.5)$. This ratio of B(E2) values is only about one-half that predicted by the vibrational model and raises some serious question about the validity of this model. These authors [23]) also found a large B(M1) value for the $2_2^+ \rightarrow 2_1^+$ in ^{110}Cd as well as for other even-A cadmium nuclei. This raises further question about the vibrational description of these medium-weight, even-A nuclei since in this picture M1 transitions should be strictly forbidden. Our data on the beta population of the 2_1^+ and 2_2^+ states in ^{110}Cd also indicate probable differences in the structures of these two states. We find a log ft value of 7.0 to the 2_2^+ state at 1475.1 keV. In contrast, we find that the log ft to the 2_1^+ state at 657.5 keV is 5.6. This same pattern of log ft values for allowed beta transitions to the corresponding two 2^+ states has been observed in other similar nuclei.

The level at 1783.3 keV is significantly populated by β-decay with a log ft value of 6.8. Since allowed transitions with such high log ft values are not uncommon in this region we prefer the allowed assignment, in view of the fact that $(1, 2)^-$ states are not usually expected so low in excitation. As this level deexcites to the 0^+ ground state and the 2^+ excited state at 657.5 keV, its J^π values can be limited to $(1, 2)^+$.

A (0^+) level at 1473.4 keV discussed earlier is not expected to be populated directly by β-decay. As was mentioned earlier the branching ratio $I(817.4)/I(1475.5)$ does not exclude the possibility of weak gamma-ray cascades into the (0^+) level at 1473.4 keV. The present γ-ray intensities indicate that the sum of the intensities of the γ-rays populating the 1475.2 keV level is 0.28 ± 0.12 relative to the 657.4 keV γ-ray taken as 100. The γ-rays at 1603 and 1630 keV were seen in coincidence with the 1475.5 keV γ-ray and therefore they must populate the 2^+, 1475.2 keV level. The 603.6, 1976, 2002 or 2122 keV γ-rays are possible candidates for populating the (0^+) 1473.4 keV level. Of these transitions, the 603.6 keV γ-ray must be excluded as it deexcites the 3^- level at 2078.8 keV. The 1976 keV γ-ray deexcites a level at 3451.1 keV, which

decays substantially to the 4^+ level at 1540.9 keV but not to the 0^+ ground state, and this makes it unlikely that it populates the (0^+) level at 1473.4 keV. The 2002 keV γ-ray was seen in coincidence only with the 817.4 keV γ-ray, although the sensitivity for observing coincidences is higher at the 1475.5 keV gate. This supports the possibility that the 2002 keV γ-ray populates the 0^+ level at 1473.4 keV. Finally, the 2122 keV γ-ray deexcites a $(1, 2)^+$ level at 3596 keV which in turn deexcites substantially to the 0^+ ground state. It is, therefore, conceivable that the 2122 keV γ-ray populates the (0^+) level at 1473.4 keV.

The level at 2078.8 keV is not populated by β-decay ($\log ft > 7.8$) and it decays only to 2^+ levels below. This information is consistent with the previous assignment [13,15]) for this level as the 3^-, one-phonon octupole vibration, but indicates that the energy measured by McGowan et al. (2051 keV) was somewhat low.

All the levels above 2786.5 keV, with the exception of the 3193.8 and 3451.1 keV levels, are rather strongly populated by β-decay ($\log ft < 6.2$) and they all decay to the 0^+ ground state. This information limits the J^π values to $(1, 2)^+$ for these levels. Of these, the levels at 3077.9, 3101.4, 3313.3 and 3770 keV decay to the 3^- state at 2078.8 keV or to the 4^+ state at 1540.9 keV. This information leaves 2^+ as the most probable assignment for each of these four levels.

The levels at 2786.5, 2868.3, 2974.1 and 3401.2 keV decay to the 2^+ level at 657.5 keV with an intensity at least 10 times greater than to the 0^+ ground state. On the basis of this information arguments in favour of the 2^+ versus 1^+ can be made on grounds of single-proton estimates for the relative transition probabilities, although the value 1^+ cannot be excluded as a possibility.

The levels at 3193.8 and 3451.1 keV are populated by allowed electron capture ($\log ft$ 6.0 and 5.7, respectively) and they were observed to decay to the 4^+ state at 1540.9 keV but not to the 0^+ ground state. This information favors J^π assignments of 3^+.

Finally, the levels at 1731.5, 1809.0, 2355.5 and 2463.1 keV are not populated significantly by β-decay and from the present information these J^π values cannot be limited any further than $(1, 2, 3)^\pm$.

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