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Observation of high spin levels in ^{131}Cs from ^{131}Ba decay

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Abstract. The γ- and conversion electron spectra following ^{131}Ba ε-decay are investigated, using HPGe detector and mini-orange electron spectrometer. Attention is particularly focussed on identifying weak transitions associated with low energy high spin levels in ^{131}Cs level scheme earlier inferred in reaction studies but not yet observed in ^{131}Ba decay. Our experiment identifies 15 new gammas and 6 new conversion lines in this decay. Internal conversion coefficients and multipolarities of several transitions are determined. Five new levels (3 with $I^\pi = 7/2^+$ and one each with $I^\pi = 9/2^+$ and $11/2^-$) are introduced in the ^{131}Cs level scheme based on our observations taken together with the results from reaction studies. Spin-parity assignments to a few other levels are also suggested.

Keywords. Radioactivity; ^{131}Ba beta decay; γ and ce measured HPGe; miniorange; internal conversion coefficient; multipolarities; ^{131}Cs level scheme.

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Medium-weight odd-mass spherical nuclei, with the odd-nucleon placed in the configuration space bounded by 50 and 82 magic numbers, normally have the lowest negative parity state with spin-parity $I^\pi = 11/2^-$ [1]. This state corresponds to the unique parity $h_{11/2}$ shell model orbital. Being a high-spin non-normal parity state, it is not directly populated in β-decay studies and is connected only through high multipole γ-ray transitions with other low-spin states. Accordingly, identification of this $11/2^-$ state in decay studies needs careful investigation of rather weak transitions. Our recent γ and conversion electron study of ^{147} Nd decay [2] had identified the $11/2^-$ level in ^{147}Pm at 647 keV. Heavy-ion reaction studies [3] have indicated the $11/2^-$ level in ^{131}Cs at 775.3 keV with a 279.1 keV stretched E1 transition from it to a $9/2^+$ level at 496.2 keV. Also a transfer reaction study [4] has suggested a number of levels with $I^\pi = 7/2^+$ in ^{131}Cs in the 600–1300 keV excitation energy range. However, ^{131}Ba ε-decay studies reported so far [5–11] have failed to identify these levels in ^{131}Cs. Our present investigation of the γ and conversion electron spectra following ^{131}Ba ($I^\pi = 1/2^+$) decay is directed towards identifying such weak transitions which may be associated with these high spin ($I = 7/2, 9/2, 11/2$) levels. By using this focussed approach, the present work also aims at deducing spin-parity for some other as yet

unassigned levels mentioned in decay studies. A preliminary report of these investigations was presented in a symposium [12].

The experimental set-up and procedure are the same as described in our recent reports on ^{147}Nd [2] and ^{125}Sb decays [13]. The γ-ray peaks were analysed using the computer code FIT [14] and EG&G ORTEC's software package GAMMAVISION. Using our γ energies and the indicated location of the various high spin levels from reaction studies as input, precise energies of these levels were determined using the computer code GTOL [15]. The conversion electron measurements employed the mini-orange spectrometer described in our earlier reports [2,13,16]. The internal conversion coefficients (ICC) were determined employing the normalised-peak-to-gamma (NPG) method. In the present study, the nuclear data sheets (NDS) adopted value [11] for the K-shell ICC $\alpha_{\mathrm{K}}(496) = 0.0102(8)$ for the 496 keV M1 transition in ^{131}Cs was used as the standard for normalisation. The transition multipolarities were then deduced from a comparison of our experimental ICC values with the Hager and Seltzer [17] theoretical results for specific multipolarities computed using the HSICC code [15].

A portion each of the singles γ and the conversion electron spectra from our experiment is shown in figure 1a and 1b. In addition to the observation of all the 62 γs listed for this decay in the latest NDS [11], our study identifies 15 γs not reported earlier. The data on these new γs and a few other inter-related γs are listed in table 1. This table also includes data for six new conversion electron lines, which have not been reported earlier [11]. The revised level scheme for ^{131}Cs, as shown in figure 2, was obtained using the GTOL code [15] incorporating all the 77 transitions observed in our experiment. As an illustration of the application of Ritz combination principle to deduce the level energies, we list below the three combinations which yields 775.3(9) keV energy for the $11/2^-$ level, in agreement with the value 775.3(5) keV quoted in NDS [11].

$$1043.96(6) - 268.71(8) = 775.25(24)$$

$$496.06(7) + 279.17(2) = 775.23(12)$$

$$657.63(6) + 117.69(13) = 775.3(9)$$

In figure 2, we show only the 22 (out of a total of 77) transitions listed in table 1, which connect the newly introduced levels or levels with new I^π assignments. The placement of the other 55 γs is the same as reported in nuclear data sheets [11]. The new results from our experiment are briefly discussed in the following paragraphs.

First, we discuss the newly introduced ^{131}Cs levels corresponding to those suggested in the particle transfer reaction study ^{133}Cs(p,t) wherein the target $I^\pi = 7/2^+$; in this experiment, the $L = 0$ transfer definitely points to an $I^\pi = 7/2^+$ assignment for the resultant level, albeit with no precise level energy. This reaction study [4] had concluded $L = 0$ transfer to ^{131}Cs levels at 78.7 keV, 661 keV, 1044 keV and 1258 keV which may be seen in ^{131}Ba decay ($Q^+ = 1370$ keV); only the 78.7 keV $7/2^+$ state has been reported [11] in decay studies to date. Our experiment establishes a $7/2^+$ level at 1043.96 keV, based on four newly observed γs, interconnecting it to other known levels, as detailed in table 1 and figure 2; its $I^\pi = 7/2^+$ assignment is confirmed on the basis of the observed E2 transition to the 585.04 keV $3/2^+$ state and the M2 transition to the 775.3 keV $11/2^-$ state. We also establish a $7/2^+$ level at 1257.89 keV based on three decay γs (newly observed) to other known levels; its I^π assignment is confirmed by the observed E2 transition to the 596.33 keV $3/2^+$ state. The NDS evaluators [11] had tentatively assigned $I^\pi = 7/2^+$ (based on

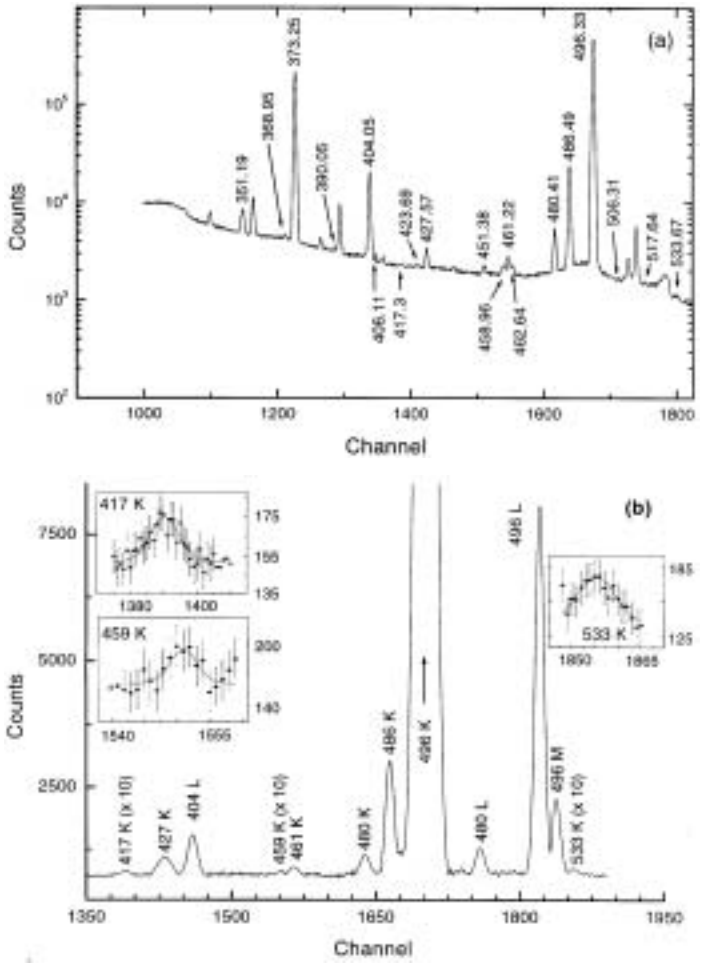

Figure 1. A portion of the typical (**a**) singles γ-ray spectra recorded with a 60 cc HPGe detector and (**b**) conversion electron spectra recorded with a mini-orange electron spectrometer, corresponding to transitions in ^{131}Cs following ^{131}Ba ε-decay. The three weak transitions, shown with ($\times$10) label, are all scaled up by a factor of 10 to be visible with the neighbouring intense peaks and are also shown as insets with the respective error bars.

$L(p,t) = 0$) to the 657.61 keV level seen in β-decay wherein [11] this level had three interconnecting γs; none of these had a known multipolarity. Our experiment identifies three additional interconnecting γs for this level and also deduces M3 multipolarity for its decay transition to 123.80 keV $1/2^+$ level, thus confirming its I^π assignment. The (p,t) experiment [4] had also suggested an $L = 2$ transfer level around 764 keV; we identify a level at 763.97 keV (based on two interconnecting γs) with $I^\pi = (3/2^+, 5/2^+)$ assignment from the deduced (M1,E2) multipolarity for the connecting transition from the 1170.26 keV $3/2^+$ level.

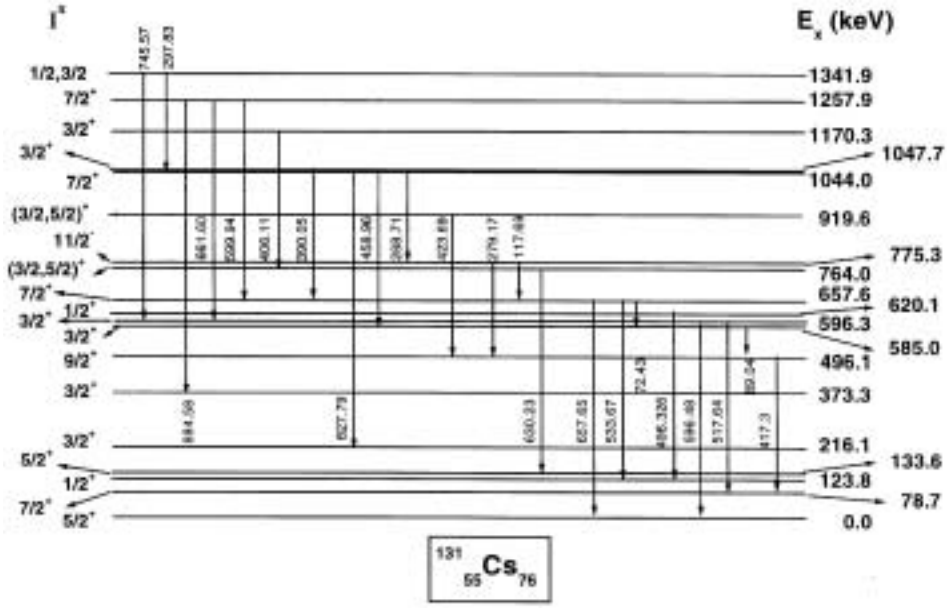

Figure 2. Revised level scheme of ^{131}Cs from ^{131}Ba ε-decay showing placement of the γs of table 1. The labels on the left are the updated spin-parity I^{π} assignments and on the right are the level energies in keV to one decimal place. The vertical lines with arrows show the 22 transitions listed in table 1 with the labels denoting the respective transition energy (in keV).

Next, we look for, in our decay spectrum, transitions indicative of the $I^{\pi} = 9/2^{+}$ (496.2 keV) and $11/2^{-}$ (775.3 keV) levels reported earlier in an (HI, $3n\gamma$) study [3]. Our experiment locates a level at 496.06 keV on the basis of four newly identified γs; $I^{\pi} = 9/2^{+}$ assignment for this level is established through the (M1,E2) multipolarity deduced by us for its decay γ to the 78.72 keV $7/2^{+}$ level, taken together with the observed stretched E1 transition to it for $11/2^{-}$ level and the in-band $\Delta I = 2$ E2 transition from it to the $5/2^{+}$ ground state in the earlier (HI,$3n\gamma$) study [3]. We introduce the 775.3 keV $11/2^{-}$ level in our decay scheme based on three newly identified interconnecting γs, with the I^{π} assignment supported by the M2 multipolarity deduced by us for the transition connecting it to the 1043.96 keV $7/2^{+}$ level, taken together with the E1 multipolarity reported earlier [3] for its decay gamma to the 496 keV $9/2^{+}$ level.

In summary, our study has been able to correlate the data on ^{131}Cs levels as revealed through three essentially non-overlapping lines of investigations, namely the β-decay studies, (HI, x$n\gamma$) reaction study, and the (p,t) two-particle transfer study. Our decay study has introduced the 775.3 keV $11/2^{-}$ and the 496.06 keV $9/2^{+}$ levels (which had earlier been reported only in a heavy-ion reaction study), the 1043.96 keV and 1257.89 keV, both $7/2^{+}$ levels, and 763.97 keV ($3/2^{+}$,$5/2^{+}$) level (all of which had earlier been indicated in an unpublished transfer reaction study) in the revised level scheme of ^{131}Cs. Unambiguous spin-parity assignments have been made to the above-mentioned first four levels and the 657.63 keV $7/2^{+}$ and 596.33 keV $3/2^{+}$ levels based on the multipolarities determined from our experiment confirming the assignments suggested in earlier reaction studies. These

Table 1. γ and conversion electron data for new transitions observed in our study of ^{131}Ba ε-decay. The successive columns from the left list transition energies (in keV) in ^{131}Cs, relative γ-intensities ($I_\gamma = 100$ for 496 keV γ), corresponding K-conversion electron energies (with K-shell binding energy in ^{131}Cs taken as 35.985 keV), relative K-conversion electron intensities, internal conversion coefficients α_K, the deduced multipolarity, and the rounded off energy (keV) and spin-parity I^π of the initial and final energy levels in ^{131}Cs for the corresponding transition. The numbers within parentheses in columns 1–5 list the assigned uncertainty for the last one/two digits of each entry. This table also includes the earlier reported [11] transitions superscripted 'a' and 'b' (explained in corresponding footnotes) and the starred normalising transition with $E_\gamma = 496.326(5)$.

E_γ (keV)	I_γ	E_{ce} (keV)	I_{ce}	ICC(α_K)	Multipolarity	$E_i(I^\pi) \rightarrow E_f(I^\pi)$
72.43(10)	0.020(3)					$658(7/2^+) \rightarrow 585(3/2^+)$
89.04(13)	0.008(1)					$585(3/2^+) \rightarrow 496(9/2^+)$
117.69(13)	0.045(16)					$775(11/2^-) \rightarrow 658(7/2^+)$
268.71(8)	0.019(5)	232.74(14)	0.39(6)	0.21(7)	M2	$1044(7/2^+) \rightarrow 775(11/2^-)$
279.17(2)	0.025(12)					$775(11/2^-) \rightarrow 496(9/2^+)$
297.83(15)	0.008(1)					$1342(1/2,3/2) \rightarrow 1044(7/2^+)$
390.05(16)[a]	0.0041(4)					$1048(3/2^+) \rightarrow 658(7/2^+)$
406.11(21)	0.044(20)	370.4(4)	0.07(5)	0.016(14)	M1+E2	$1170(3/2^+) \rightarrow 764(3/2^+,5/2^+)$
417.3(3)	0.006(3)	381.3(4)	0.009(4)	0.015(10)	M1+E2	$496(9/2^+) \rightarrow 78(7/2^+)$
423.69(25)	0.0042(5)					$919(3/2^+,5/2^+) \rightarrow 496(9/2^+)$
458.96(10)	0.012(1)	423.01(18)	0.012(5)	0.010(5)	E2	$1044(7/2^+) \rightarrow 585(3/2^+)$
496.326(5)*	100	460.339(9)	100	0.0102(8)	M1	$620(1/2^+) \rightarrow 124(1/2^+)$
517.64(7)[b]	0.007(2)					$596(3/2^+) \rightarrow 79(7/2^+)$
533.67(17)[a]	0.003(1)	497.67(27)	0.017(4)	0.06(2)	M3	$658(7/2^+) \rightarrow 124(1/2^+)$
596.48(14)[b]	0.0037(4)					$596(3/2^+) \rightarrow 0(5/2^+)$
599.94(11)	0.0034(4)					$1258(7/2^+) \rightarrow 658(7/2^+)$
630.23(17)	0.0078(9)					$764(3/2^+,5/2^+) \rightarrow 134(7/2^+)$
657.65(11)[a]	0.0074(7)					$658(7/2^+) \rightarrow 0(5/2^+)$
661.60(8)	0.014(2)	625.52(12)	0.0053(14)	0.0039(12)	E2	$1258(7/2^+) \rightarrow 596(3/2^+)$
745.57(6)[b]	0.0025(4)					$1342(1/2,3/2) \rightarrow 596(3/2^+)$
827.79(12)	0.0077(8)					$1044(7/2^+) \rightarrow 216(3/2^+)$
884.58(20)	0.0048(5)					$1258(7/2^+) \rightarrow 373(3/2^+)$

[a]These gammas, reported earlier [11] and also observed by us in ^{131}Ba decay, are included here in the context of our $I^\pi = 7/2^+$ assignment to the 657.63 keV level.
[b]These gammas, reported earlier [11] and also observed by us in ^{131}Ba decay, are included here in the context of our $I^\pi = 3/2^+$ assignment to the 596.33 keV level.

additions to the level scheme of the transitional nucleus ^{131}Cs are expected to be valuable for further structure studies in this region.

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