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Decay of mass-separated ^{143}Ba to levels in ^{143}La

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The decay of mass-separated ^{143}Ba to levels in ^{143}La has been investigated using γ-ray spectroscopy in both the singles and coincidence modes. Of 69 γ rays ascribed to the decay of ^{143}Ba, 59 were placed in a level scheme which represents the first information on excited states in ^{143}La. A total of 19 levels up to a maximum energy of 2347 keV were observed. The resulting level scheme is compared with that of ^{141}La and systematics of odd-A La isotopes are discussed.

[RADIOACTIVITY ^{143}Ba [from ^{235}U(n,f)]; measured $T_{1/2}$, E_γ, I_γ, $\gamma\gamma$-coin Ge(Li) detectors; ^{143}La deduced levels, J, π. Mass-separated ^{143}Ba activity.]

I. INTRODUCTION

Little information exists on the level structure of odd-A La nuclei with neutron number greater than the magic number 82. This is due to the difficulty of obtaining nuclear structure information for nuclei on the neutron-rich side of stability. Level information for the above nuclei exists only for ^{141}La.[1] The half-life of ^{143}Ba was first measured by Wahl *et al.*[2] to be 12 ± 2 sec. A value of 13.2 ± 0.3 sec was later obtained by Runnalls, Troutner, and Ferguson.[3] Both values were obtained indirectly by milking ^{143}La from the ^{143}Ba parent. A direct measurement of the ^{143}Ba half-life by Tamai *et al.*[4] after separation from fission products by paper electrophoresis resulted in a value of 20 sec which was accepted by the Nuclear Data Group.[5] They also measured the γ spectrum with a Ge(Li) detector and assigned eight γ rays to ^{143}Ba decay. A decay scheme was not given, and no information on excited states of ^{143}La exists in the literature.

We expect the low-lying states in odd-A La nuclei near $N=82$ to be mostly positive parity and described in terms of the odd proton coupled to phonon vibrations of the Ba core. It is well known that even-even Ba nuclei become increasingly soft towards deformation as neutron pairs are subtracted from the $N=82$ nucleus ^{138}Ba, and ground-state rotational bands have been reported[6,7] for ^{126}Ba and ^{128}Ba. Henry and Meyer[8] have observed low-lying negative-parity states in ^{133}La which can be interpreted in terms of a Coriolis-coupling model in which the odd particle is coupled to a rotating core.

It is interesting to determine if there is a softening of La nuclei as neutron pairs are added beyond $N=82$ and to see to what extent it corresponds to the effect observed for nuclei with $N<82$. We thus undertook this study on the decay of mass-separated ^{143}Ba to levels in ^{143}La to extend the systematics of odd-A La nuclei to the neutron-rich side of the $N=82$ line.

II. EXPERIMENTAL METHODS

Sources of mass-separated ^{143}Ba were produced by the TRISTAN on-line isotope separator facility at the Ames Laboratory research reactor. The details of this system have been described elsewhere.[9]

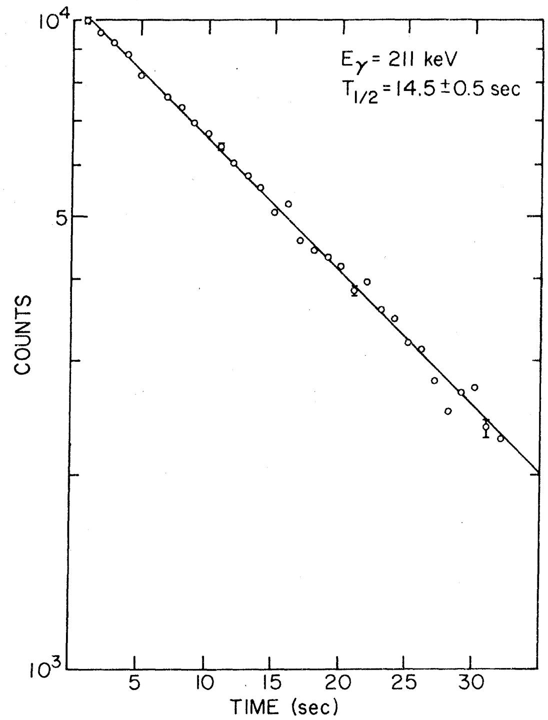

FIG. 1. Half-life curve for the 211-keV γ ray from ^{143}Ba decay.

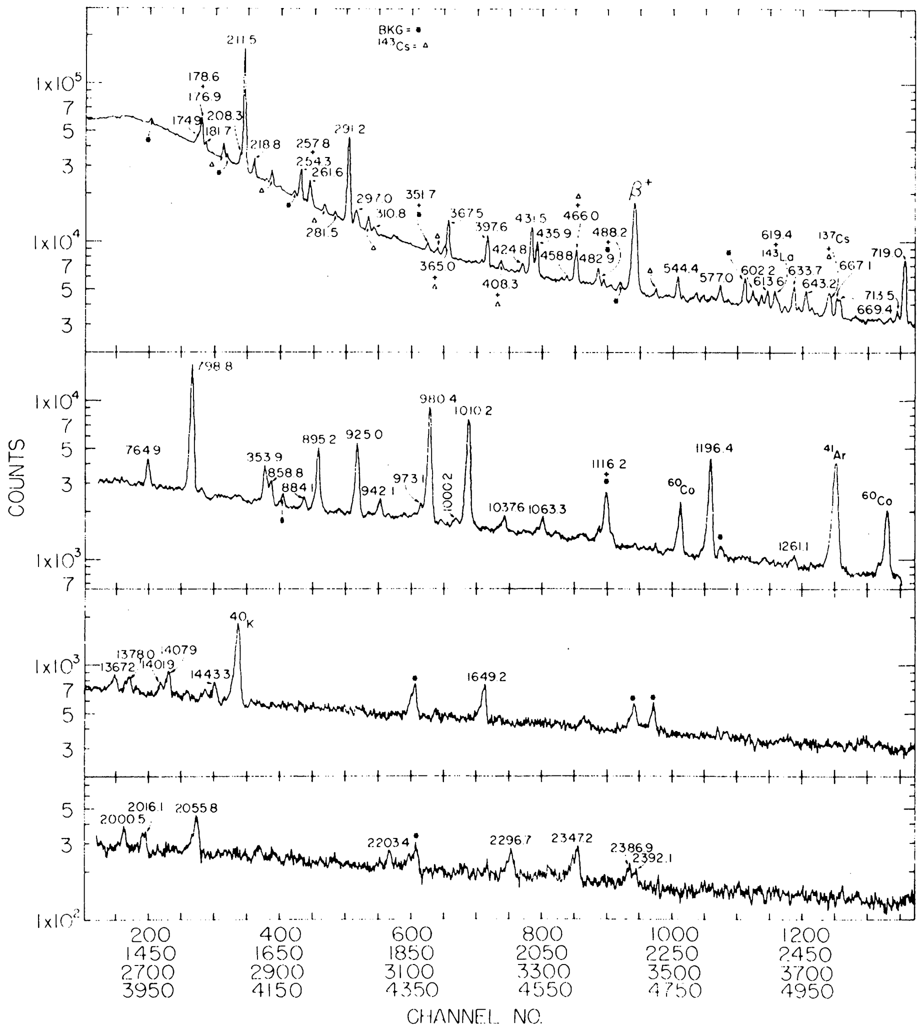

FIG. 2. γ-ray spectrum of ^{143}Ba decay. The energies given in keV are for γ rays from ^{143}Ba decay.

In view of the discrepancies between earlier measurements[2-4] the ^{143}Ba half-life was remeasured. The $A = 143$ ion beam from TRISTAN was collected on a movable tape for 35 sec. After an 8-sec delay, the γ-ray spectra were multiscaled into 32 time bins, each of 1-sec duration. Each spectrum contained 512 channels of information. The decay curve obtained for the strong 211-keV γ ray after subtraction of background and correction for live-time is shown in Fig. 1. The value of 14.5 ± 0.5 sec was obtained from a weighted least-squares fit to the data. This result is in fair agreement with the earlier indirect[2,3] measurements, but disagrees with the value of 20 sec obtained by direct measurement[4] and accepted by the Nuclear Data Group.[5]

For γ singles measurements the $A = 143$ ion beam from TRISTAN was collected on a movable tape in the moving tape system described in Ref. 9. In typical runs activity was collected for 40 sec and moved to a shielded secondary tape stop position. After a delay of 4 sec to minimize interference from short-lived ^{143}Cs and ^{143}Xe a Ge(Li) detector with 10% efficiency was used to accumulate data for 40 sec. This process was repeated until sufficient statistics had been obtained.

A representative singles spectrum collected for a 70-h period over an energy range from 100 to 2600 keV is shown in Fig. 2. Because of possible contamination from other members of the $A = 143$ decay chains, the ^{143}Ba singles spectrum was compared with spectra collected to optimize short-lived ^{143}Xe and ^{143}Cs, long-lived ^{143}La, and background. In Fig. 2 all γ rays from ^{143}Ba decay are indicated by energy, and strong peaks from contaminants are designated by isotope or as back-

TABLE I. γ-ray transitions observed in the decay of ^{143}Ba.

Energy [a] (keV)	Relative intensity [a]	Energy [b] (keV)	Relative intensity [b]	Placement
29.8 [c]				30–0
174.9 ±0.3	30 ±4			466–291
176.88 ±0.20	45 ±7			643–466
178.56 ±0.09	139 ±8			208–30
181.69 ±0.10	33 ±3			211–30
208.31 ±0.12	34 ±5			208–0
211.49 ±0.07	1000 [d]	211.3	1000 [d]	211–0
218.75 ±0.09	54 ±5			219–0
254.32 ±0.12	105 ±7			466–211
257.8 ±0.6	3 ±1			466–208
261.56 ±0.15	62 ±6			291–30
281.5 ±0.5	10 ±2			925–643
291.22 ±0.05	338 ±20			291–0
297.02 ±0.08	37 ±4			941–643
310.77 ±0.15	16 ±3			1010–699
351.7 ±0.5	14 ±3			643–291
365.0 ±0.5	7 ±2			831–466
367.54 ±0.13	80 ±5			1010–643
387.1	<3	387.1	286 ±33	
397.59 ±0.06	58 ±4			1408–1010
408.3 ±0.3	21 ±3			699–291
424.84 ±0.15	19 ±3			643–219
431.54 ±0.06	120 ±8	431.6	524 ±62	643–211
435.87 ±0.09	86 ±6			466–30
458.81 ±0.25	11 ±3			925–466
466.0 ±0.4	43 ±4			466–0
482.88 ±0.08	36 ±3			1408–925
488.2 ±0.4	7 ±2			699–211
515.6	<5	515.6	243 ±70	
544.41 ±0.08	41 ±4			1010–466
577.05 ±0.13	31 ±4			1408–831
602.21 ±0.14	23 ±4			1067–466
613.68 ±0.18	28 ±4			643–30
619.40 ±0.13	33 ±5			831–211
633.73 ±0.09	51 ±5			925–291
643.15 ±0.10	40 ±4			643–0
667.07 ±0.12	29 ±3			Unplaced
669.44 ±0.11	27 ±3			699–30
713.5 ±0.25	18 ±4			925–211
718.99 ±0.06	164 ±11			1010–291
764.88 ±0.13	59 ±6			1408–643
798.78 ±0.05	559 ±35	799.2	745 ±80	1010–211
853.94 ±0.20	54 ±10			854–0
858.81 ±0.15	43 ±5			1067–208
884.10 ±0.17	22 ±3			2292–1408
895.17 ±0.06	144 ±10			925–30
925.03 ±0.06	174 ±12	925.7	208 ±78	925–0
942.13 ±0.17	32 ±4			1408–466
973.1 ±0.3	13 ±3			Unplaced
980.45 ±0.06	379 ±25	981.7	483 ±73	1010–30
1000.2 ±0.5	14 ±3			Unplaced
1010.25 ±0.07	324 ±24	1011.3	558 ±78	1010–0
1037.6 ±0.25	22 ±3			1067–30
1063.34 ±0.17	9 ±2			Unplaced
1116.2 ±0.4	31 ±4			1408–291
1196.36 ±0.09	238 ±17			1408–211
1261.1 ±0.4	10 ±3			Unplaced
1367.2 ±0.25	21 ±3			2292–925
1378.0 ±0.3	15 ±3			1408–30

TABLE I. (*Continued*)

Energy [a] (keV)	Relative intensity [a]	Energy [b] (keV)	Relative intensity [b]	Placement
1401.9 ±0.5	11 ±3			Unplaced
1407.87 ±0.19	23 ±3			1408-0
1443.3 ±0.25	20 ±3			2297-854
1649.23 ±0.18	34 ±4			2292-643
2000.5 ±0.4	14 ±3			2292-291
2016.1 ±0.4	18 ±3			Unplaced
2055.8 ±0.3	32 ±3			2347-291
2203.4 ±0.7	10 ±3			Unplaced
2296.7 ±0.5	18 ±4			2297-0
2347.2 ±0.4	29 ±4			2347-0
2386.9 ±0.7	11 ±3			Unplaced
2392.1 ±0.6	12 ±3			Unplaced

[a]Results from this work.
[b]Results from Ref. 4.
[c] Energy determined from level scheme. Evidence for γ ray in LEPS spectrum marginal. Transition probably highly converted.
[d]Intensity normalized to 1000 for the 211-keV γ ray.

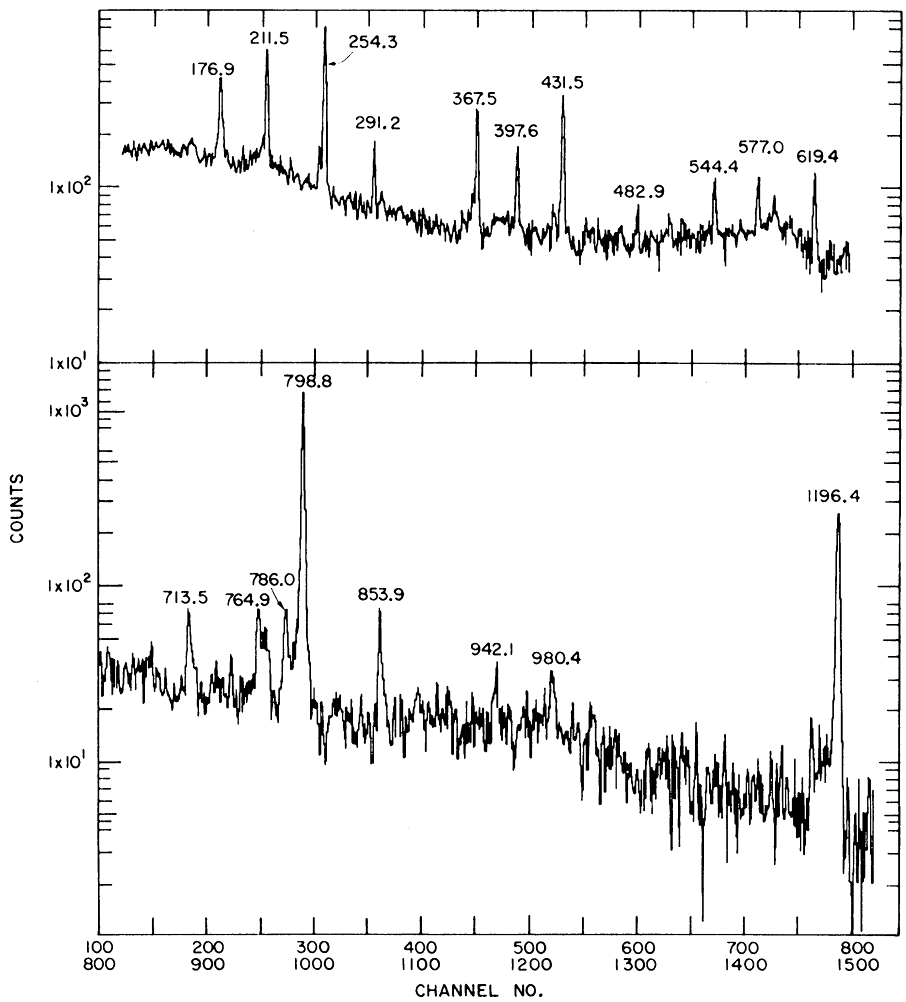

FIG. 3. Coincidence spectrum of the 211-keV gate.

ground (BKG). The γ rays at 352, 365, 408, 466, 488, and 1116 keV are mixed containing ^{143}Ba and ^{143}Cs or background. The spectrum from 0 to 400 keV was measured using a LEPS Ge(Li) detector. The only γ ray due to ^{143}Ba decay observed below 174 keV was a possible weak one at 29.8 keV. No γ rays from ^{142}Ba decay were observed even though ^{142}Ba could be produced by delayed-neutron emission from ^{143}Cs.

Standard γ lines from ^{22}Na, ^{57}Co, ^{60}Co, ^{133}Ba, ^{182}Ta, ^{207}Bi, and ^{228}Th were used to provide energy and intensity calibrations for the detectors and map the nonlinearities of the systems. Spectrum peak centroids and areas were determined for the singles data by applying[10] a nonlinear least-squares fit of a skewed-Gaussian fit function to the data. A total of 69 γ rays were assigned to ^{143}Ba decay. Their energies, intensities, and placements are given in Table I and compared with the results of Tamai *et al.*[4] We did not observe γ rays seen by them at 387.1 and 515.6 keV, and upper limits on the intensities are given in the table.

Coincidence measurements were performed with two Ge(Li) detectors with 10% efficiency in 180° geometry. Constant-fraction timing was used. The timing sequence for activity collection, delay, and data accumulation was similar to that for the singles measurements. About 4×10^6 events were stored in a 4096×4096 channel array covering a 3200×3200-keV interval. The coincidence spectra for various γ rays were reconstructed by a computer search of the event data and compared with suitable "Compton background" spectra. The spectrum in coincidence with the 211-keV γ ray is shown in Fig. 3, and the coincidence results are summarized in Table II.

III. DECAY SCHEME AND DISCUSSION

The above data were used to construct the decay scheme for ^{143}Ba shown in Fig. 4. We were not able to measure the β feeding to the ground state or the 30-keV level. In order to determine approximate log*ft* values for our levels a crude value for β feeding to the 1408-keV level was determined by comparison in our singles spectrum of the intensity of the 1196-keV γ ray from ^{143}Ba decay and the 621-keV γ ray from ^{143}La decay. The 621-keV γ ray depopulates a level at 663 keV in ^{143}Ce which is fed[11] by 2.4% of the β strength from ^{143}La decay. Bjornstad *et al.*[12] observed the 621-keV γ ray to be a doublet of 620.6 and 621.7 keV with intensities of 100 and 47,9, respectively. The 620.6-keV γ ray is the one that depopulates the level at 663 keV. Using the above information it was determined that (7.4 ± 2.0)% of the ^{143}Ba β transitions feed the 1408-keV level in ^{143}La. From this value and our γ in-

TABLE II. $\gamma\gamma$ coincidences in the decay of ^{143}Ba.

Gating transition (keV)	Coincident γ transitions (keV)
175, 177, 179	175, 177, 179, 208, 211, 219, 254, 258, 281, 291, 368, 398, 436, 459, 466, 483, 765, 859, 1649
182	177, 254, 368, 432, 799, 1196
211	177, 254, 368, 398, 432, 488, 544, 577, 619, 714, 765, 786[a], 799, 854, 942, 1196, 1649
219	175, 297, 368
254	177, 182, 211, 365, 368, 398, 459, 544, 577, 602, 765, 942, 949[a]
258	177, 179, 208, 368
262	175, 177, 368, 634, 719, 1116
281	175, 177, 179, 182, 208, 211, 254, 262, 291, 466, 483
291	311, 352, 398, 408, 634, 719, 1116, 2001, 2056
297	219, 425, 643, 1111[a]
311	179, 208, 211, 254, 291, 408, 669
368	175, 177, 179, 182, 208, 211, 254, 262, 291, 425, 432, 436, 466, 577, 643
398	177, 179, 182, 211, 254, 262, 291, 368, 719, 799, 980, 1010
425	219, 297, 368
432	182, 368, 398, 765, 1649
436	177, 368, 544, 602, 765, 942
459	179, 208, 211, 254, 291
466	177, 368, 398
483	179, 208, 211, 254, 262, 281, 291, 895, 925
544	179, 182, 208, 211, 254, 262, 291, 398, 436, 466
577	211, 619
602	211, 254, 291, 436, 667
614	765
619	211, 577
634	262, 291
643	368, 765, 1649
669	311
714	182, 211
719	262, 291, 398
765	175, 177, 211, 254, 291, 432, 436, 614, 643
799	182, 211, 398
854	1443
859	179, 208
884	211
895	483
925	483, 1367
942	179, 182, 211, 254, 291, 436, 466
973	435[a]
980	398
1010	398
1116	262, 291
1196	181, 211, 884
1443	854
1649	177, 211, 254, 291, 432, 643
2001	291
2056	291

[a] γ ray seen only in coincidence and not placed in level scheme.

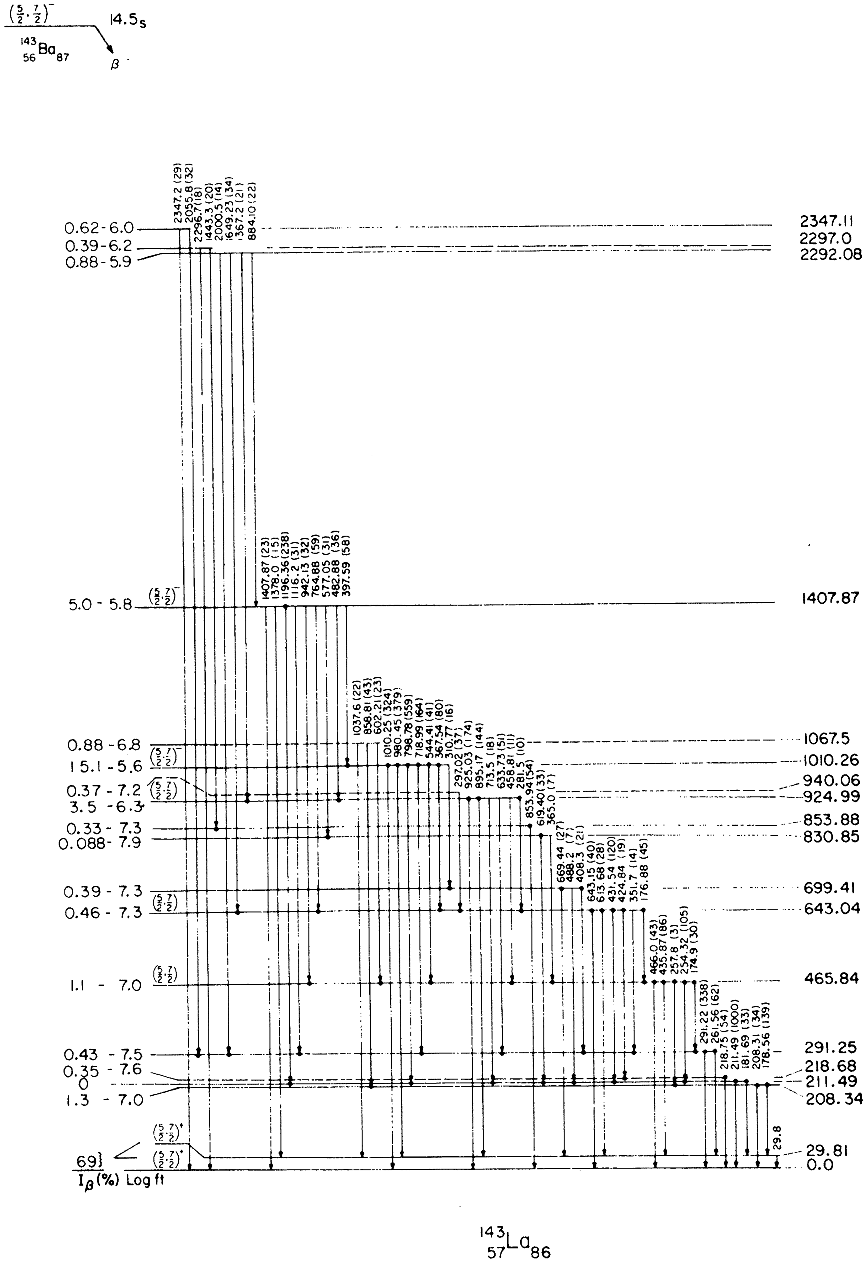

FIG. 4. Proposed decay scheme of ^{143}Ba.

tensities, β feedings to all levels except the ground state and the 30-keV level were determined. Logft values were calculated for all levels above 30 keV. A Q_β of 4200 keV was used.[5] The complete β branching, logft, and level energy information is summarized in Table III.

Levels at 30, 208, 211, 291, 466, 643, 699, 831, 925, 1010, 1408, and 2292 keV are firmly established on the basis of numerous populating and depopulating γ rays and extensive coincidence results. The level at 2347 is based on the good energy match between the energy of the 2347-keV γ

TABLE III. β branching and $\log ft$ values for ^{143}Ba decay.

Level energy (keV)	β branching (%)	Logft
0.0	69 ±22	> 5.4
29.81 ±0.10		> 5.4
208.34 ±0.09	1.3 ±0.4	7.0
211.49 ±0.06	0	
218.68 ±0.20	0.35 ±0.11	7.6
291.25 ±0.08	0.43 ±0.26	7.5
465.84 ±0.18	1.1 ±0.3	7.0
643.04 ±0.20	0.46 ±0.19	7.3
699.41 ±0.16	0.39 ±0.11	7.3
830.85 ±0.11	0.088 ±0.068	7.9
853.88 ±0.19	0.33 ±0.13	7.3
924.99 ±0.08	3.5 ±1.0	6.3 [a]
940.06 ±0.21	0.37 ±0.10	7.2
1010.26 ±0.07	15.1 ±3.7	5.6 [a]
1067.5 ±0.5	0.88 ±0.27	6.8 [a]
1407.87 ±0.07	5.0 ±1.4	5.8 [a]
2292.08 ±0.19	0.88 ±0.30	5.9 [a]
2297.0 ±0.3	0.39 ±0.11	6.2 [a]
2347.11 ±0.21	0.62 ±0.17	6.0 [a]

[a] $\log f_1 t < 8.5$, therefore corresponding β transition must have $\Delta I < 2$.

ray and the sum of the 2056- and 291-keV γ rays. The coincidence between the 2056- and 291-keV γ rays was also well established. Levels at 219, 854, 940, 1067, and 2297 keV are less firmly established even though all are supported by some coincidence information. These levels are therefore dashed in Fig. 4.

Simple shell-model arguments would imply a J^π of $\frac{7}{2}^-$ for the $^{143}_{56}Ba_{87}$ ground state due to the 87th neutron but the $^{147}_{60}Nd_{87}$ ground state is $\frac{5}{2}^-$. We therefore favor $\frac{7}{2}^-$ or $\frac{5}{2}^-$ for the ^{143}Ba ground state. The shell model would imply the ground state and 30-keV level in ^{143}La to be $g_{7/2}$ or $d_{5/2}$. There is no division of the 69% β^- feeding to the above two levels that would give $\log ft$'s above 5.9 for both levels. This implies either that one of the levels has negative parity (contrary to expectations of the simple shell model) or that this situation is an exception to the $\log ft$ rules of Raman and Gove.[13]

The density of excited states in ^{143}La below 500 keV is double that in ^{141}La.[1] A similar trend is noted[14] in ^{137}La and ^{135}La which can be interpreted in terms of a softening of the Ba core when moving away from the $N = 82$ line. The $\log ft$ values for β decay to levels in ^{143}La below 500 keV are characteristic of first-forbidden β transitions and imply that most of these levels have positive parity. An interpretation of these levels in terms of a single proton weakly coupled to vibrations of the Ba core seems reasonable. For levels at 466, 643, 925, 1010, and 1408 keV the intensities for transitions depopulating to the ground state and the 30-keV level, respectively, are within a factor of 2. We thus favor a spin of $\frac{5}{2}$ or $\frac{7}{2}$ for these levels.

The most significant result of this study is the identification of three negative parity levels at, 1010, 1408, and 2292 keV on the basis of the low values of $\log ft$ for the β transitions populating them (we assume negative parity for the ^{143}Ba ground state on shell-model grounds). The two levels at 1010 and 1408 keV are fed by 65% of the total β strength to states in ^{143}La above 30 keV. It is also interesting to note that γ transitions of significant strength are observed between the 1408-keV and the other two negative-parity states even though such transitions are hindered relative to decay to lower-lying states both by energy and the fact that they are $M1/E2$ in character rather than $E1$.

A possible interpretation of the negative-parity states could be in terms of a weak-coupling model where the $h_{11/2}$ proton is coupled to the one-phonon vibration of the ^{142}Ba core. The first excited 2^+ state[15] in ^{142}Ba is at 360 keV but the energy of the $h_{11/2}$ state in this region is not known. The corresponding state[14] in ^{135}La is at 787 keV. It therefore seems unlikely that all three of our negative-parity levels could be accomodated by a weak-coupling picture. Another possible interpretation of the negative parity levels would be in terms of a particle-plus-rotor coupling scheme similar to that used[8] to interpret levels in ^{133}La. The above model was used to calculate the negative parity levels in ^{143}La. It was not possible to reproduce the number of relatively low-lying low-spin negative-parity states observed in this work.

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