Half-life and internal conversion electron measurements in low-lying levels of ^{125,127}Ba

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The level properties in the low energy region of ^{125,127}Ba were studied through the decays of ^{125,127}La by using the JAERI on-line mass separator (JAERI-ISOL). The half-lives of the excited states and the internal conversion coefficients were determined for the first time by the β-γ delayed coincidence technique and by conversion electron measurements, respectively. The half-life of the long-lived isomeric state of ^{127}Ba (1.93 s) was determined by spectrum multiscaling measurements. Although the detailed decay schemes have been proposed, no evidence of a parity doublet has been observed. The level properties with respect to the transition probabilities are well interpreted by the Nilsson model.

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I. INTRODUCTION

Decay spectroscopy using on-line mass separators has the advantage of allowing the study of level properties in the low energy region, including band head information, since γ transitions between low-spin states can be measured more intensively under lower background conditions than can those with in-beam spectroscopy measurements. Neutron-deficient nuclides of ^{125,127}Ba have been studied by means of in-beam spectroscopy, and the level structures for high-spin states were successfully interpreted within the framework of the IBFM model [1–5]. Decay studies of these nuclides have rarely been reported. Therefore, the last evaluations in Refs. [6, 7] were mainly based on in-beam studies. In 1991, the possibility of static octupole deformation, similar to that of the $A=145$ and 225 regions proposed, was proposed for the $A=130$ region by Cottle [8]. The presence of static octupole deformation is represented by parity doublets, which have equal spins and opposite parity levels of rotational bands with alternating bands. The $E1$ transitions between parity doublets are characterized by a two to four orders of magnitude enhancement compared to those of more normal cases. The $^{127-130}$Ba isotopes were successively studied by in-beam conversion electron measurements to investigate for parity doublets, and no evidence of them was observed [9,10]. These studies, however, focused only on the conversion electron measurements; the transition probabilities were not measured. It is necessary to measure not only the conversion electrons, but also the half-lives of the excited states in order to explain this feature.

The aim of this investigation was to study the level properties of ^{125,127}Ba in the low energy region, focusing on a search for $E1$ transitions, and to study their properties by measuring the half-lives of low-lying excited states. The half-lives and conversion electrons were measured for the first time through the decays of ^{125,127}La, by means of a delayed coincidence technique and a cooled Si(Li) detector, respectively. The expected enhanced $E1$ transitions were not observed. Level properties based on the Nilsson model are proposed.

II. EXPERIMENTAL PROCEDURE

The radioactivities of ^{125,127}La were produced with the heavy-ion-induced fusion evaporation reactions of ^{nat}Mo(^{32}S,pxn) with a 160-MeV ^{32}S beam (~50 pnA) from a tandem accelerator (MP20) of JAERI. The target thickness of natural Mo was about 4 mg/cm^2. Using an oxidation technique [11], La isotopes were extracted from a thermal ion source in a chemical monoxide compound (LaO^+) and separated with an on-line mass separator (JAERI-ISOL). The mass-separated beam was implanted into an aluminum-coated Mylar tape, which was computer controlled and periodically moved into a counting position. The tape was moved every 160 and 640 s for ^{125}La and ^{127}La, respectively, to decrease their daughter activities. For the long-lived isomer of ^{127}Ba, the mass at $A=127$ was set to separate metallic ions of Ba in order to reduce feeding from ^{127}La to the isomeric states of ^{127}Ba, since the metal of lanthanum is less ionized than is its monoxide.

A planar-type Ge detector (ORTEC LEPS: 25 mm$^{\phi}$ $\times$15 mm^{t}) and a plastic scintillation detector were used for β-γ delayed coincidence measurements at the counting position. Beta particles were detected with a 1-mm-thick bifurcated plastic scintillation detector and the transporting tape was sandwiched between the detectors to provide a high detection efficiency. A constant fraction discriminator (Canberra 2126) was used for the timing signal from the LEPS to minimize the sensitivity to the peak centroid on the γ-ray energy in these measurements. Before and after the measurements of mass-separated radioactivity, prompt timing distribution curves in the low energy region were measured by means of an external conversion technique [12]. Fluorescence x rays of niobium, indium, barium, samarium, and ytterbium, which were generated by γ rays from ^{134}Cs, ^{154}Eu, ^{170}Tm, and ^{198}Au, were adopted. This enabled us to obtain a reliable prompt curve between 12 and 800 keV. The typical time resolution (ΔT) around 50 keV was approximately 12 ns in this experiment. The spectrum multiscaling

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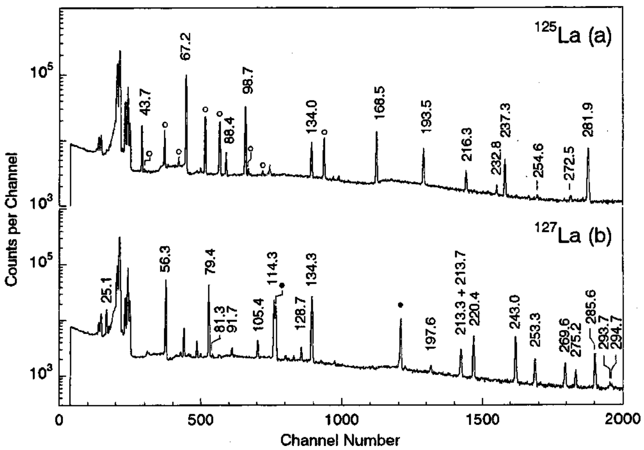

FIG. 1. Low energy portions of the γ-ray spectra in the decay of ^{125}La (a) and ^{127}La (b) obtained with a LEPS. The open and closed circles indicate the γ rays associated with the decay of their daughter or granddaughter nuclei, respectively.

method, which was used to measure 16 spectra in 5-s intervals, was adopted to determine the half-life of a long-lived isomer with the LEPS.

Internal conversion electrons were measured with a cooled Si(Li) detector (500 mm^2$\times$3 mm, 2.5-keV full width at half maximum at 976-keV electrons of ^{207}Bi). Simultaneously, γ rays were measured with a 20% HPGe detector with 180° geometry in order to obtain the peak intensity ratios between the electrons and γ rays. The source-to-detector distance was 2.5 cm in both cases. Some conversion

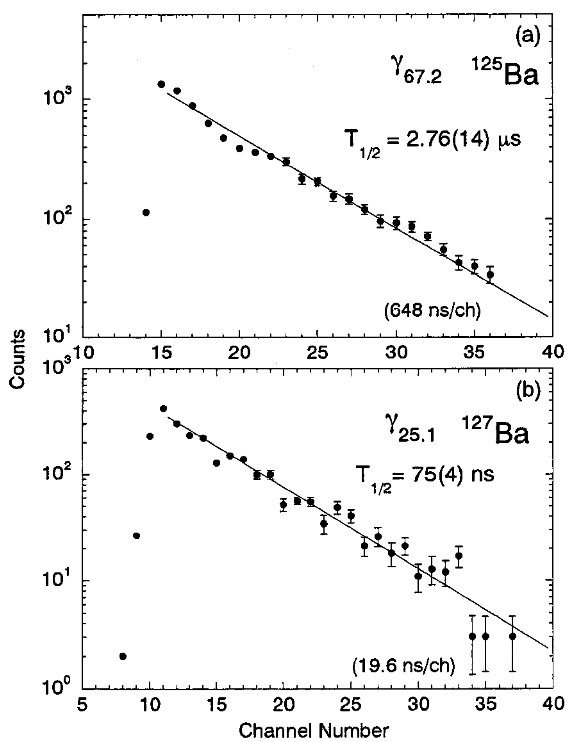

FIG. 2. Time distribution curves of the 67.2- and 25.1-keV γ transitions in the decays of ^{125}La (a) and ^{127}La (b), respectively.

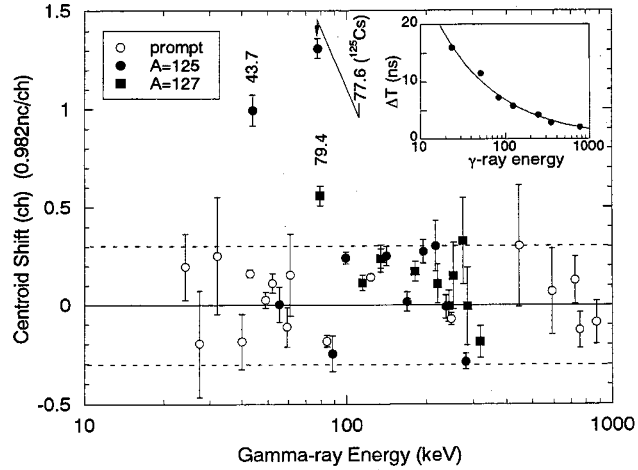

FIG. 3. Peak centroid shifts of γ transitions obtained with mass-separated beams of $A = 125+16$, $127+16$ and prompt time distributions obtained by the external conversion technique. The inset shows the typical time resolution in this experiment.

coefficients of transitions below 100 keV were determined by means of x-γ or γ-γ coincidence measurements with the LEPS and the Ge detector with 180° geometry.

In addition, γ-ray intensity measurements were performed with the HPGe detector and the LEPS with source-to-detector distances of 10 and 5 cm, respectively. The full energy peak efficiencies for the detectors were determined using standard sources of ^{56}Co, ^{133}Ba, ^{152}Eu, and ^{241}Am. In order to correct for the summing effects, the total efficiencies were determined by using sources of ^{60}Co, ^{137}Cs, and ^{170}Tm. The uncertainties of the full energy peak efficiencies were evaluated as follows: 2% below 240 and 1.5% above 240 keV for the HPGe detector, 3% below 50 keV and 2%

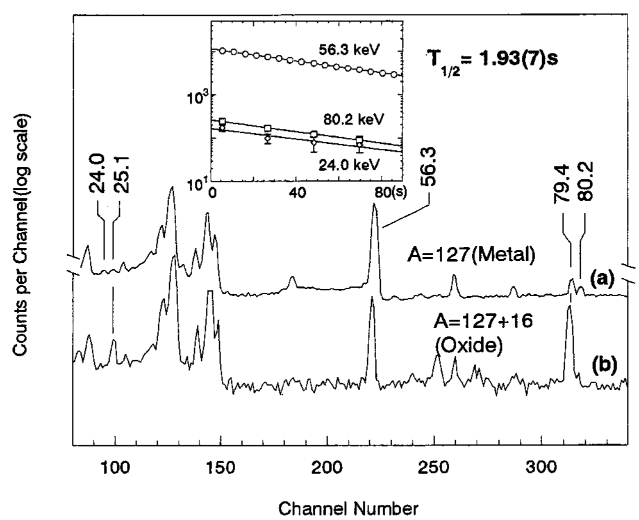

FIG. 4. Comparison of the γ-ray spectra obtained with a metallic beam [$A = 127$ (a)] and an oxide beam [$A = 127+16$ (b)]. The inset shows decay curves of the 80.2-, 56.3-, and 24.0-keV γ rays of the ^{127m}Ba isomeric transitions.

TABLE I. Relative intensities of the γ rays associated with the decay of ^{127m}Ba.

	Relative intensity	
E_γ (keV)	Present	Liang *et al.*[a]
24.0	10.5(20)	~6
56.3	1000	1000
80.2	6.1(7)	

[a]Taken from Ref. [13].

between 50 and 240 keV, and 1.5% above 240 keV for the LEPS.

III. RESULTS

A. Half-lives of the excited states of ^{125,127}La

The low energy portions of the γ-ray spectra associated with the decay of ^{125,127}La are shown in Figs. 1(a) and 1(b), respectively. Time distribution curves for the 67.2-keV γ ray in ^{125}La and the 25.1-keV γ ray in ^{127}La, which were obtained by gating the corresponding γ-ray peaks in Figs. 1(a) and 1(b) in the delayed coincidences, are shown in Figs. 2(a) and 2(b), respectively. The half-lives of the $67.2+X$-keV level in ^{125}La and the 81.4-keV level in ^{127}La were deduced for the first time to be 2.76(14) μs and 75(4) ns from the slopes, respectively. (Each level scheme will be discussed later.) The half-lives of the other levels were determined by using the centroid shifts method (Fig. 3). No discrepancies were observed between the two prompt timing distribution curves that were obtained with the preceding and following calibration measurements. The systematic uncertainties of 0.3 channels were evaluated from the deviation of the obtained centroid shifts. Because they correspond to 0.3 ns for the mean-life, the systematic uncertainties of the deduced half-lives were evaluated to be 0.2 ns. The half-lives of the 43.7-keV level in ^{125}La and the 159.6-keV level in ^{127}La were deduced to be 0.7(2) ns from the centroid shift of the

TABLE II. Experimental internal conversion coefficients of transitions in ^{125,127}Ba.

			Theoretical[a]					
E_γ (keV)	α	Present	$E1$	$E2$	$E3$	$M1$	$M2$	Assigned multipolarity
^{125}Ba								
43.7[b]	K	8.9(5)	1.80	7.71		9.37		$M1/E2$
67.2[b]	K	0.9(3)	0.577	3.69		2.71		$E1$
98.7	K	1.0(4)	0.207	1.28		0.895		$M1/E2$
134.0	K	0.36(14)	0.0870	0.486		0.378		$M1/E2$
168.5	K	0.21(8)	0.0460	0.236		0.200		$M1/E2$
193.5	K	0.12(4)	0.0315	0.149		0.137		$M1/E2$
216.3	K	0.13(4)	0.0233	0.104		0.101		$M1/E2$
237.3	K	0.056(17)	0.0182	0.0770		0.0791		$E2$ ($M1/E2$)[c]
281.9	K	0.046(14)	0.0116	0.0446		0.0510		$E2$ ($M1/E2$)[c]
^{127}Ba								
24.0[d]	T	$(0.6-1.6)\times10^3$			8.5×10^4		1.1×10^3	$M2$ ($E3\leqslant2\%$)
25.1[e]	T	6.9–20.2	1.73	5.37×10^2		8.46		$M1$
56.3[b]	K	5.0(4)	0.928	5.50		4.53		$M1/E2$
79.4	K	2.0(1)	0.928	1.26		0.666		$M1/E2$
114.3	K	1.0(5)	0.135	0.803		0.591		$M1/E2$
128.7	K	1.2(5)	0.0972	0.553		0.423		$M1/E2$
134.3	K	0.45(18)	0.865	0.483		0.376		$M1/E2$
213.3+213.7[f]	K	0.099(30)	0.0242	0.108		0.105		$M1/E2$
220.4	K	0.097(30)	0.0222	0.0975		0.0963		$M1/E2$
243.0	K	0.078(25)	0.0171	0.0713		0.0742		$M1/E2$
253.3	K	0.087(30)	0.0148	0.0625		0.0665		$M1/E2$
269.6	K	0.062(28)	0.0154	0.0513		0.0564		$E2$ ($M1/E2$)[c]
285.6	K	0.047(15)	0.0153	0.0428		0.0484		$M1/E2$
318.7	K	0.035(10)	0.00846	0.0305		0.0364		$E2$ ($M1/E2$)[c]

[a]Taken from Ref. [14].
[b]Deduced by x-γ coincidences.
[c]These transitions are favorably assigned to $E2$ (see text).
[d]Deduced by γ-ray intensity balance.
[e]Deduced by γ-γ coincidences.
[f]Doublet peak.

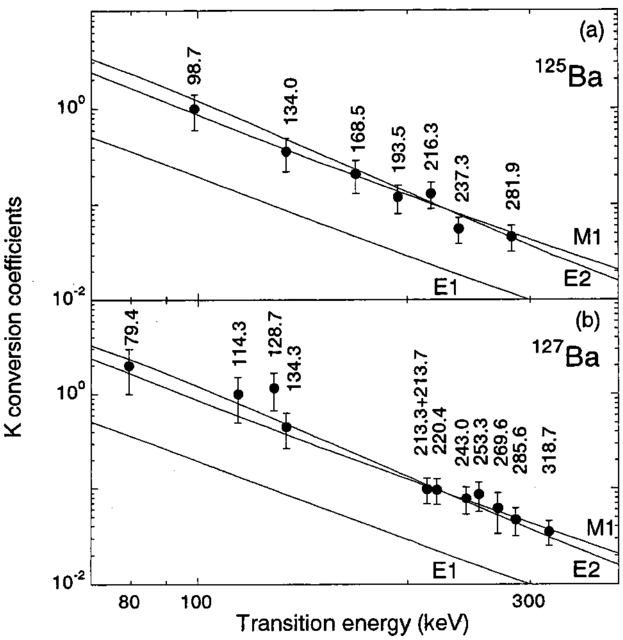

FIG. 5. Experimentally deduced K conversion coefficients of transitions in ^{125}Ba (a) and ^{127}Ba (b).

43.7-keV transition and 0.4(2) ns from that of the 79.4-keV transition.

Further, the half-life of ^{127m}Ba was deduced to be 1.93(7) s from the decay curves of the 24.0-, 56.3-, and 80.2-keV γ rays by spectrum multiscaling measurements with an $A = 127$ beam (inset in Fig. 4), which mainly consisted of the metallic state of barium. The contribution of ^{127}La decay to the 56.3-keV γ ray was corrected using the other γ-ray intensities of ^{127}La. The present result was in good agreement with the previous value of 1.9(2) s by Liang *et al.* [13]. The relative intensities of the three γ rays associated with the decay of ^{127m}Ba were obtained much more precisely than were those of Liang *et al.* [13] (Table I).

B. Internal conversion coefficients, multipolarities, and parity determination

Above 100 keV, the $\alpha_K s$ were determined by taking the peak intensity ratios of the electrons to the simultaneously measured γ rays. These values were normalized by using the pure $E2$ $(2^+ \rightarrow 0^+)$ 230-keV transition in ^{124}Ba. Some conversion coefficients of α_K and α_T below 100 keV were deduced as indicated in Table II by means of x-γ or γ-γ coincidence methods. The experimental values and the assigned multipolarities are shown in Fig. 5 and are also listed in Table II together with the theoretical values by Rösel *et al.* [14].

In ^{125}Ba, the α_K values of the 43.7- and 67.2-keV transitions were deduced from the x-γ coincidence method with the 281.9- and 521.6-keV γ rays, respectively. [The 521.6-keV γ ray is not shown in the decay scheme (see Fig. 7 below), but the coincidence relation was certainly confirmed.] In this method, the coincidence events with β^+ particles were also taken into account to distinguish the K x rays from the originating EC decay and the internal conversion process. For example, the α_K of the 43.7-keV transition was deduced as follows:

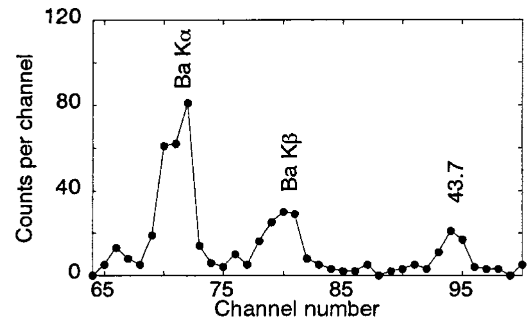

FIG. 6. Low energy portion of the coincident spectrum obtained with the LEPS gated by the 281.9-keV γ ray and β^+ ray.

$$\alpha_K = \frac{I_{K\mathrm{x}}}{I_{43.7}} \cdot \frac{1}{\omega_K},$$

where $(I_{K\mathrm{x}}/I_{43.7})$ is the measured intensity ratio of the K x rays to the 43.7-keV γ ray in the gated spectrum with the 281.9-keV γ ray and β^+ particles (Fig. 6), and ω_K is the evaluated K-fluorescence yield [15]. Other contributions to the K x rays from the other coincident γ rays were negligibly small. The multipolarities of the 43.7- and 67.2-keV transitions were assigned as $M1/E2$ and $E1$ transitions, respectively. The other α_K values of the 98.7-, 134.0-, 168.5-, 193.5-, 216.3-, 237.3-, and 281.9-keV γ transitions were deduced from the conversion electron measurements, and the multipolarities were assigned to $M1/E2$ [see Table II and Fig. 5(a)].

The α_K of the 56.3-keV transition in ^{127}Ba was deduced from the x-γ coincidence method with the 318.7-keV γ ray and assigned to an $M1/E2$ transition. Using the cascade relation between the 25.1- and 56.3-keV γ rays, the α_T of the 25.1-keV transition was deduced from the intensity balance in the gated spectrum by the 334.8-keV γ ray as follows:

$$\alpha_T(25.1) = \frac{\{1+\alpha_T(56.3)\} \cdot I_{56.3} - I_{25.1}}{I_{25.1}},$$

where $I_{56.3}$ and $I_{25.1}$ are the measured intensities in the gated spectrum with 318.7-keV γ rays. Assuming the multipolarity of the 56.3-keV transition to $M1$ or $E2$, the α_T value of the 25.1-keV transition was deduced to be 6.9–20.2. The calculated value by Rösel *et al.* [14] supports that the 25.1-keV transition is $M1$. Similarly, the α_T value of the 24.0-keV transition was deduced to be $(0.6-1.6)\times 10^3$ from the γ-ray relative intensity (Table I) balance. Given that the calculated values by Rösel *et al.* [14] are 1.1×10^3 and 8.5×10^4 for $M2$ and $E3$, respectively, the 24.0-keV transition can be considered mainly an $M2$ transition. The other α_K values of the 79.4-, 114.3-, 128.7-, 134.3-, 220.4-, 243.0-, 253.3-, 269.6-, 285.6-, and 318.7-keV γ transitions associated with the decay of ^{127}La were deduced from the internal conversion electron measurements [Fig. 5(b)]. Since the values for the 213.3- and 213.7-keV transitions could not be deduced by the conversion electron spectrum individually, they were

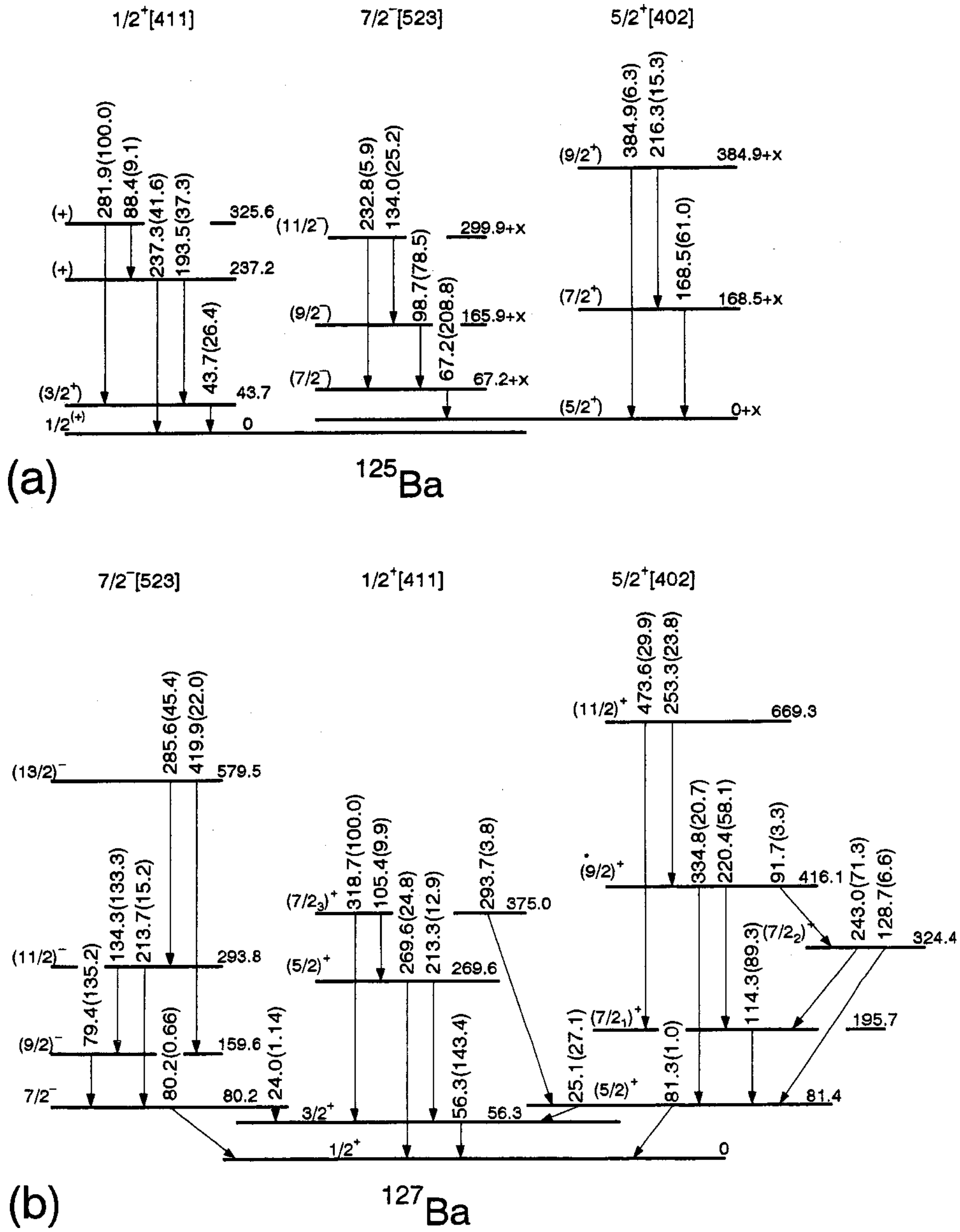

FIG. 7. Proposed partial decay schemes of ^{125}La (a) and ^{127}La (b).

treated as a doublet peak. The multipolarities of these transitions were assigned to $M1/E2$.

Partial decay schemes of ^{125}La and ^{127}La are proposed in Figs. 7(a) and 7(b), respectively. (Detailed discussions are in the next section.) The parities of the levels were determined based on the determined multipolarities, as follows. The ground state of ^{127}Ba had been determined by means of laser spectroscopy to be an even-parity state [16], whereas that of ^{125}Ba is unknown; thus, only changes in the parities could be proposed in ^{125}Ba. Because the 43.7-keV γ ray in ^{125}Ba is the $M1/E2$ transition, the parity does not change at the 43.7-keV level. The parity of the first excited $0+X$-keV state, which has been proposed to be the $X\sim20$-keV state, could not be determined in this experiment. The parity is considered to change at the $67.2+X$-keV level, given that the 67.2-keV γ ray was determined to be the $E1$ transition. Consequently, the $67.2+X$-, $165.9+X$-, and $299.9+X$-keV levels represent the same parity states, while the 43.7-, 237.2-, 325.6-, $0+X$-, $168.5+X$-, and $384.9+X$-keV levels represent the opposite ones.

In ^{127}Ba, according to Ref. [7], the spin parties of the ground state, 56.3- and 80.2-keV levels are $\frac{1}{2}^+$, $\frac{3}{2}^+$, and $\frac{7}{2}^-$, respectively. The assigned multipolarities of $M1/E2$ and $M2$ for the 56.3- and 24.1-keV γ transitions in this experiment were consistent with the previous results. The 81.4-keV level was assigned to even parity, since the 25.1-keV transition was determined to be $M1$. According to these results, the levels at 159.6, 293.8, and 579.5 keV were determined to be odd parity, while the levels at 269.6, 375.0, 195.7, 324.4, 416.1, and 669.3 keV were determined to be even-parity states. These results support findings in a previous evaluation [7]. Precise decay schemes of ^{125,127}La, including the γ-ray intensities and γ-γ coincidence relationships up to 2 MeV, are under construction.

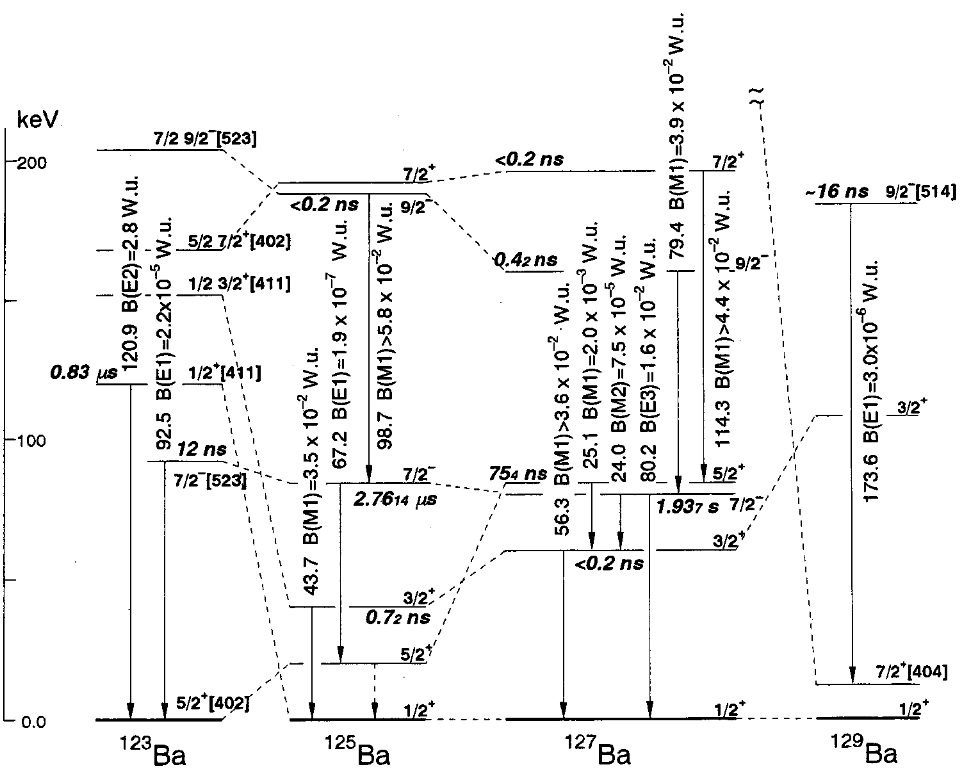

FIG. 8. Energy systematics and reduced transition probabilities of low-lying levels in the $^{123-129}$Ba.

IV. DISCUSSION

The structures of high energy levels observed by in-beam spectroscopy of the neutron-deficient Ba isotopes were well interpreted by the IBFM model. Although the systematic behavior of the low-lying levels in $^{123-129}$Ba has also been interpreted within the framework of the IBFM model, that model did not necessarily succeed in explaining their complicated aspects. In Refs. [6,7], the band structures are interpreted based on the Nilsson model. The energy systematics, including the transition intensities deduced in the present experiment, are shown in Fig. 8. They change abruptly not only between ^{123}Ba and ^{125}Ba, but also between ^{127}Ba and ^{129}Ba. These features are very different from those of Xe isotopes. The ground states change from $\frac{5}{2}^+$ in ^{123}Ba to $\frac{1}{2}^+$ in ^{125}Ba. These ground states are proposed to correspond to the $\frac{5}{2}^+[402]$ and $\frac{1}{2}^+[411]$ orbits, respectively. The $\frac{1}{2}^+[411]$ orbit rises up (to) 120 keV in ^{123}Ba. These systematics will be discussed based on transition probabilities.

Some level properties are discussed according to the hindrance factors (F_w) of the $M1$ transitions. The deduced F_ws of the 43.7- and 98.7-keV γ rays in ^{125}Ba and the 25.1-, 56.3-, and 79.4-keV γ rays in ^{127}Ba are given in Table III (they are presented in Fig. 8 in W.u.). In a comparison of the Xe isotopes in this region, the F_ws of the $M1$ transitions between the first $\frac{3}{2}^+$ levels and the $\frac{1}{2}^+$ ground states in ^{123,125,127,129}Xe, which are probably the same band members, are <35, 39(3), 36(1), and 36(1), respectively [17,6,7,18]. They have hindrance factors of almost the same order. Other $M1$ transitions between different band members in the Xe isotopes have hindrance factors of one order of magnitude larger. In the case of Ba, the situation is expected to be quite similar. However, the value of the 25.1-keV transition is one order of magnitude larger than those of the other transitions. This means that the 25.1-keV transition has properties different from those of the other transitions, and that the 25.1-keV transition depopulates between different bands. This is con-

TABLE III. Deduced partial half-lives ($t_{1/2}$) and hindrance factors (F_w) of transitions in ^{125,127}Ba.

Nuclide	E_γ (keV)	Multipolarity	$t_{1/2}$ (s)	F_w
^{125}Ba	43.7	$M1$	$8.5(32)\times10^{-9}$	29(8)
	67.2	$E1$	$4.6(3)\times10^{-6}$	$5.3(3)\times10^{6}$
	98.7	$M1$	$<0.4\times10^{-9}$	<17
^{127}Ba	25.1	$M1$	$7.3(4)\times10^{-7}$	508(27)
	56.3	$M1$	$<3.4\times10^{-9}$	<27
	79.4	$M1$	$1.1(5)\times10^{-9}$	26(13)
	114.3	$M1$	$<3.4\times10^{-10}$	<23
^{127m}Ba	24.0	$M2$	2047	1.3×10^{4}
	80.2	$E3$	3523	56

sistent with the previous assignments; that is, the 43.7-keV level in ^{125}Ba is the band member of the ground state that probably has the $KI^{\pi}[Nn_3\Lambda]$ of the $\frac{1}{2}$ $\frac{3}{2}^+[411]$ state, and the 56.3-keV level in ^{127}Ba has a similar configuration. On the other hand, the 81.4-keV level in ^{127}Ba is not a member of the ground state, but the band head of the $\frac{5}{2}^+[402]$ orbit. The larger hindrance factor of the 25.1-keV transition may be explained by differences in the asymptotic quantum numbers of n_3 and Λ.

The 120.9-keV γ transition of ^{123}Ba, which is assigned as pure $E2$ ($\frac{1}{2}^+[411] \rightarrow \frac{5}{2}^+[402]$), has a half-life of 0.83(6) μs ($F_w = 1.4$) [19]. If the X ($\sim$20)-keV $E2$ γ transition in ^{125}Ba has a hindrance factor of the same order, the $0+X$ ($\sim$20)-keV level possibly has a half-life of about 0.1 ms and the α_T value of the X ($\sim$20)-keV $E2$ transition is about 1.9×10^3. Thus, the γ-ray intensity is estimated to be 0.25, approximately. It is almost impossible to observe such a weak transition below 40 keV in the decay spectrum of ^{125}La.

As mentioned above, regarding the transition probabilities, the present results certainly support the previous assignments in Refs. [6,7]. Thus, the band structures in ^{125,127}Ba [Figs. 7(a) and 7(b)] can be favorably interpreted as a rotational band structure, not as an alternating band structure. Moreover, no evidence of parity doublets was shown. A hindered $E1$ transition was observed in ^{125}Ba in this experiment ($F_w = 5.3 \times 10^6$). An $E1$ transition was also observed in ^{123}Ba between the same band members as those in ^{125}Ba in our previous study [20], and its hindrance factor F_w was 4.5×10^4. Both findings can be favorably interpreted as indicative of transitions having $\Delta n_3 = 2$, in violation of the asymptotic selection rule [21]. These interpretations are certainly consistent with the previous level assignments; that is, the $0+X$- and the $67+X$-keV levels correspond to the band heads of $\frac{5}{2}^+[402]$ originating from $g_{7/2^+}$ and the band head of $\frac{7}{2}^-[523]$ originating from $h_{11/2^-}$, respectively. Although such $E1$ transitions were not observed in ^{127}Ba, a hindered $E1$ transition of 173.6 keV ($F_w = 3.3 \times 10^5$) was observed in ^{129}Ba [18]. This also suggests the presence of no static octupole deformation in the Ba isotopes in this region.

A long-lived isomer that deexcites to the $\frac{1}{2}^+$ and $\frac{3}{2}^+$ levels by the 24.0-keV γ ray ($M2$) and the 80.2-keV γ ray ($E3$), respectively, appears at 80.2 keV. These transitions having high multipolarities support the differences in asymptotic quantum numbers between the levels, and the assignment for the 80.2-keV level to the $\frac{7}{2}^-[523]$ band head is consistent with the experimental multipolarity. The F_ws for $M2$ and $E3$ are 1.3×10^4 and 56, respectively. The hindered $E3$ transition also suggests a lesser degree of octupole deformation.

According to the proposed decay scheme, the 237.3- and 289.1-keV γ rays in ^{125}La and the 213.7-, 269.6-, and 318.7-keV γ rays in ^{127}La in Table II are favorably assigned to the $E2$ transitions. Three $\frac{7}{2}^+$ levels, at 195.7 ($\frac{7}{2}{}_1^+$), 324.4 ($\frac{7}{2}{}_2^+$), and 375.0 keV ($\frac{7}{2}{}_3^+$), in ^{127}La were previously proposed. Although the assignments of parities herein are consistent with previous results, the property of the $\frac{7}{2}{}_2^+$ level could not be clarified in this experiment.

V. CONCLUSIONS

The half-lives and internal conversion coefficients of the excited states in ^{125,127}Ba were deduced by the decays of ^{125,127}La. The Nilsson model can explain the low-lying levels, and the present results support the previously proposed level schemes. Consequently, an alternating parity structure indicative of octupole deformation was not observed in this region, and the hindered $E1$ transitions observed are consistent with the nonexistence of parity doublets.

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