Eur. Phys. J. A **23**, 33–39 (2005)
DOI 10.1140/epja/i2004-10067-y

THE EUROPEAN PHYSICAL JOURNAL A

Levels in ^{127}La fed by the ^{127}Ce beta-decay

H. Iimura[1,a], M. Asai[1], S. Ichikawa[1], J. Katakura[1], M. Magara[1], A. Osa[1], M. Oshima[1], N. Shinohara[1], and H. Yamamoto[2]

[1] Japan Atomic Energy Research Institute, Tokai, Ibaraki 319-1195, Japan
[2] Department of Nuclear Engineering, Nagoya University, Nagoya 464-8603, Japan

Received: 26 June 2004 / Revised version: 4 August 2004 /
Published online: 8 December 2004 –
Communicated by J. Äystö

Abstract. The low-lying levels in ^{127}La have been studied through the β-decay of ^{127}Ce ($T_{1/2} = 29\,$s) produced by bombarding a $^{\rm nat}$Mo target with a 185-MeV ^{35}Cl beam. Reaction products were on-line mass-separated, and γ-ray singles and γ-γ coincidence measurements were performed. Conversion electrons were also measured and multipolarities of transitions have been derived. The half-life of the 210.9-keV level was determined to be $(1.9 \pm 0.3)\,$ns by the β-γ delayed coincidence technique. The level scheme obtained has been compared with calculations based on the Nilsson model.

PACS. 23.20.Lv γ transitions and level energies – 27.60.+j $90 \leq A \leq 149$

1 Introduction

Neutron-deficient nuclei in the light–rare-earth region with $A \approx 130$ lie in the region close to the $N = 82$ shell gap and have been the subject of many experimental studies because calculations predict competition between spherical and deformed shapes for these nuclei. For the ^{127}La nucleus, the high-spin level structures have been studied extensively by means of in-beam spectroscopy [1–4]. However, studies of the β-decay of ^{127}Ce to ^{127}La have rarely been reported. A transition at 58.5 keV was assigned [5] to the ^{127}Ce β-decay for the first time in 1978 by using an on-line mass separator, and a half-life of $(32 \pm 4)\,$s was measured for this γ-ray and La X-rays. Later, several new γ-rays were assigned to the ^{127}Ce β-decay [6]. Recently, by using an ion-guide coupled with an on-line mass separator Genevey *et al.* [7] observed that γ-rays at 58.5 and 120.3 keV decayed with different half-lives, $(29 \pm 2)\,$s and $(34 \pm 2)\,$s, respectively, in the β-decay of ^{127}Ce, and a partial level scheme in ^{127}La was proposed. In the present work, we studied the level scheme of ^{127}La from the β-decay of ^{127}Ce, using an on-line mass-separation technique. The aim of this experiment is to obtain more information on the low-lying level scheme of ^{127}La. From the present experiment, we have observed 15 new levels and in addition determined that the 423.1-keV level has the same parity as the ground state. Our results are compared with theoretical predictions using the Nilsson model. Preliminary results of this work are given in ref. [8].

[a] e-mail: iimura@popsvr.tokai.jaeri.go.jp

2 Experiment

The experiment was performed at the tandem accelerator facility at the Japan Atomic Energy Research Institute using the reaction $^{\rm nat}$Mo(^{35}Cl, 1pxn)^{127}Ce with a 185-MeV ^{35}Cl beam. The experimental setup is almost the same as our previous one [9]. The thickness of the molybdenum targets was about 3 mg/cm^2. Reaction products were ionized in a surface ionization ion source and mass-separated electromagnetically as a 40-keV beam. In order to obtain the ^{127}Ce activity free from the Cs and Ba isobars, the monoxide ions ^{127}Ce^{16}O$^+$ were separated by setting the magnetic field at mass 143. This method [10] was not able to separate ^{127}La from ^{127}Ce, and the former was the main impurity throughout this experiment. The mass-separated ^{127}Ce activity was implanted into an aluminum-coated Mylar tape in a tape transport system and periodically transported to a measuring position, where γ-ray singles measurements were performed with a planar-type Ge detector ($25\,{\rm mm}^\phi \times 15\,{\rm mm}^t$) and a 20% HPGe detector. The decays of γ-rays were traced by taking consecutively 16 spectra counted for 4 s each. Coincidence γ-ray spectra were measured with a 32% p-type HPGe detector and a 28% n-type HPGe detector, which were mounted close to the point at which the mass-separated ion beam hit the tape.

Conversion electrons were measured with a Si(Li) detector ($500\,{\rm mm}^2 \times 3\,{\rm mm}^t$, 2.5-keV full width at half maximum for 976-keV electrons). Simultaneously γ-rays were measured with the 20% HPGe detector. Those detectors were set at 180° geometry, the source-to-detector distance

Table 1. Gamma-ray transitions observed following the decay of ^{127}Ce.

Present work		Genevey *et al.* [7]	
Energy (keV)[a]	Intensity[b]	Energy (keV)	Intensity[b]
58.5(1)	13.5(14)	58.5	20(2)
75.7(1)	3.4(4)	75.7	9(3)
75.8(3)[c]	0.2(1)[c]		
		81.6	9(3)
		91.1	4(2)
103.2(2)	0.7(1)		
115.6(2)	1.9(2)	115.5	8(2)
120.3(1)	100(10)	120.4	100(10)
		136.2	2(1)
137.5(1)	1.7(2)	137.5	5(2)
142.1(1)	1.8(2)		
176.4(1)	4.6(5)	175	2(1)
177.5(1)	8.9(9)	177.4	18(3)
179.8(1)	1.3(2)		
191.4(1)	0.9(2)		
196.0(1)	35(4)	195.9	35(3)
196.6(3)[c]	0.8(3)[c]		
226.3(1)	17.8(18)	226.3	6(1)
236.1(1)	6.6(7)	236.1	8(2)
253.0(3)[c]	13(4)[c]	253.0	18(2)
256.0(3)[c]	0.8(4)[c]		
279.7(1)	8.3(9)	279.3	10(3)
295.7(3)	0.7(4)		
300.3(1)	1.3(4)		
311.6(1)	30(3)	311.6	30(2)
		338	2(1)
		351	2(1)
367.0(1)	2.5(6)		
370.9(1)	1.5(6)		
		372.5	2(1)
394.7(1)	2.3(4)		
397.6(1)	11.7(13)	397.6	15(2)
423.1(1)	6.5(8)		
428.7(1)	20(3)[d]	428.4	13(2)
429.2(5)[c]	0.7(4)[c]		
433.1(1)	1.4(5)		
456.3(1)	16.2(17)	456.3	10(2)
491.7(1)	4.0(6)		
497.0(1)	1.5(6)		
587.3(2)	1.3(4)		
605.9(1)	3.3(4)		
627.4(2)	0.9(2)	626.5	4(1)
631.2(1)	1.2(2)		
664.5(1)	5.1(6)		
676.3(3)	1.3(3)		
678.2(3)	0.5(2)		
684.3(2)	2.4(4)	683.1	4(1)
703.2(1)	2.7(6)	702.3	7(2)
718.3(5)[c]	1.3(6)[c]	718.2	2(1)
724.3(5)[c]	0.7(4)[c]		
752.9(5)[c]	0.7(4)[c]		
764.3(3)	1.0(3)	765	3(1)
789.4(4)	1.4(5)	789	2(1)
		794.2	2(1)
800.0(2)	1.1(3)		
		809.4	3(1)
823.5(1)	4.1(5)	822.3	4(1)
861.7(1)	6.9(8)	860.5	8(2)
864.6(1)	7.6(9)	864.8	8(2)
865.8(2)	2.8(6)		
920.4(1)	3.8(6)		
951.8(4)	1.2(5)	952	3(1)
		984.9	3(1)
		1003	3(1)
		1029	2(1)
1071.9(2)	1.9(5)		
1131.0(5)[c]	1.7(8)[c]		
1135.2(4)	1.8(5)		
1137.8(3)	1.9(5)		
1147.9(5)[c]	1.0(4)[c]		
1148.2(1)	9.4(13)	1148	13(3)
1150.0(5)[c]	0.8(4)[c]		
1158.8(1)	2.2(3)		
1174.5(5)[c]	0.8(4)[c]		
1198.1(2)	1.2(3)		
1225.0(5)[c]	0.9(6)[c]		
1226.1(5)[c]	0.9(5)[c]		
1231.6(3)	1.0(4)		
1252.4(3)	2.5(6)		
1253.7(5)	1.2(5)		
1314.7(1)	3.7(5)		
1341.6(5)[c]	1.3(5)[c]		
1342.9(1)	6.7(10)		
1361.1(5)[c]	0.6(3)[c]		
1418.7(1)	1.3(3)		
1428.8(5)[c]	0.6(4)[c]		
1450.7(2)	1.6(3)		
1466.6(5)[c]	1.3(6)[c]		
1477.9(3)	1.0(2)		
1488.9(5)[c]	0.7(4)[c]		
1534.3(1)	1.5(3)		
1563.6(1)	8.5(10)		
1593.1(5)[c]	0.9(5)[c]		
1654.6(1)	5.0(7)		
1668.7(5)[c]	1.2(6)[c]		
1681.7(5)[c]	0.9(5)[c]		
1730.6(2)	2.3(6)		
1838.2(2)	1.6(4)		
1961.1(3)	0.8(2)		

(a) Number in parentheses is the uncertainty in unit of 0.1 keV.
(b) Number(s) in parentheses is the uncertainty in the last digit(s).
(c) From coincidence data.
(d) Intensity derived by subtracting out the daughter contamination.

being 2.5 cm in both cases. In order to obtain more information on the transitions, a β-γ delayed coincidence measurement was also performed, utilizing a plastic scintillation detector and the planar-type Ge detector.

3 Results

The time decay curves of intense γ-rays at 58.5, 120.3, 196.0, 226.3, and 311.6 keV are plotted in fig. 1. It can be

Table 2. Experimental conversion coefficients for transitions following the decay of ^{127}Ce.

Transition energy (keV)		Conversion coefficient ($\times10^{-2}$)(a)	Theoretical conversion ($\times10^{-2}$)(b) $E1$	$E2$	$M1$	Multipolarity
58.5(c)	T	1500(800)	100	1400	520	$M1, E2$
	L	30(20)	13	720	60	
75.7	L	10(6)	6.1	220	28	
120.3	K	40(16)	12	70	55	$M1(+E2)$
	L	5.1(22)	1.6	27	7.5	
$176.4 + 177.5$(d)	K	15(5)	4.2	21	19	
196.0	K	9(4)	3.2	15	14	$M1, E2$
	L	1.6(5)	0.42	3.6	1.9	
226.3	K	6.4(20)	2.2	9.3	9.7	$M1, E2$
	L	3.6(15)	0.28	2.0	1.3	
236.1	K	8(4)	1.9	8.1	8.7	$M1, E2$
279.7	K	≈ 4.6	1.2	4.7	5.5	$(M1, E2)$
311.6	K	3.2(11)	0.93	3.4	4.2	$M1, E2$
	L	≈ 0.9	0.12	0.62	0.55	
397.6	K	3.1(14)	0.51	1.6	2.2	$M1, E2$
423.1	K	2.4(13)	0.44	1.4	1.9	$M1, E2$
428.7	K	1.6(6)	0.42	1.3	1.8	$M1, E2$
456.3	K	≈ 1.9	0.36	1.1	1.6	$(M1, E2)$

(a) The number(s) in parentheses is the error in the last digit(s).
(b) Calculated from Hager and Seltzer [11].
(c) Total conversion coefficient calculated by gamma-ray intensity balance.
(d) Conversion coefficient calculated is for the total gamma-ray intensity and total conversion electron intensity observed for the doublet.

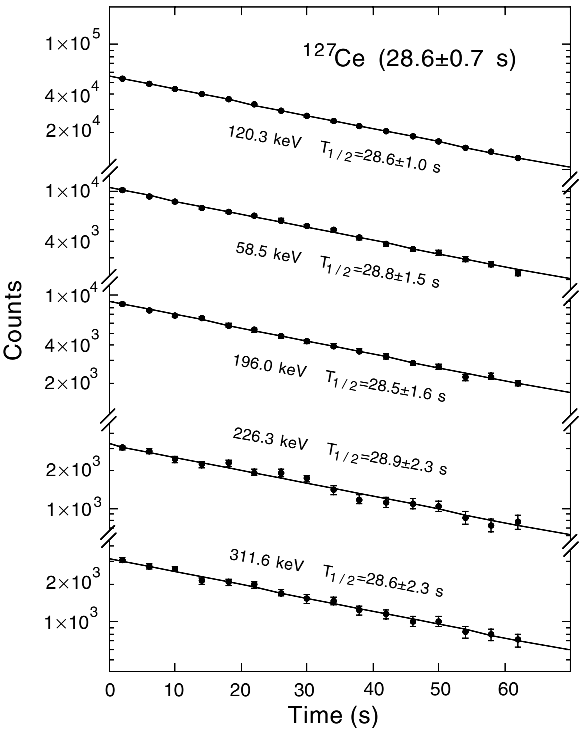

Fig. 1. Time decay curves of the main γ-rays observed in the ^{127}Ce decay.

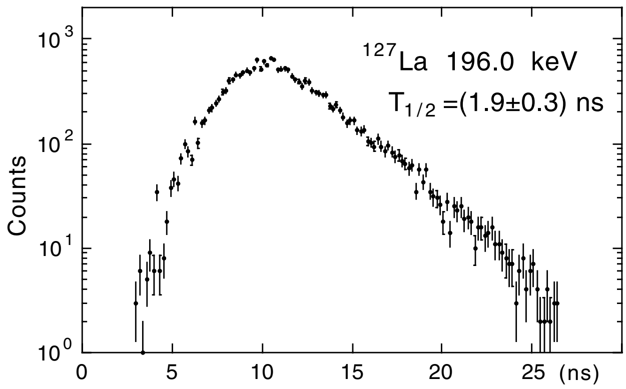

Fig. 2. A time distribution curve obtained between β^+-particles and the 196.0-keV γ-ray.

seen that the difference of the half-lives of the 58.5- and 120.3-keV γ-lines is too small to establish two independent half-lives. Other γ-lines are also seen to decay with the same half-life, and the average half-life of these five γ-lines was determined to be (28.6 ± 0.7) s. This implies that the (34 ± 2) s isomer in ^{127}Ce [7] was not produced with any significant intensity in the present work. Genevey *et al.* [7] used the systems of ^{92}Mo and ^{94}Mo targets with ^{40}Ca beams. These systems produce $A = 127$ nuclei very far from stability and hence the levels in ^{127}La are fed by β-decay of its precursors in a long $A = 127$ decay chain including low-spin isomers.

From the γ-ray singles and coincidence data, 88 γ-rays have been determined to belong to the decay of ^{127}Ce. The energies and intensities of these γ-rays are given in table 1, and compared with the results from previous studies [7]. The comparison reveals that the intensities of some

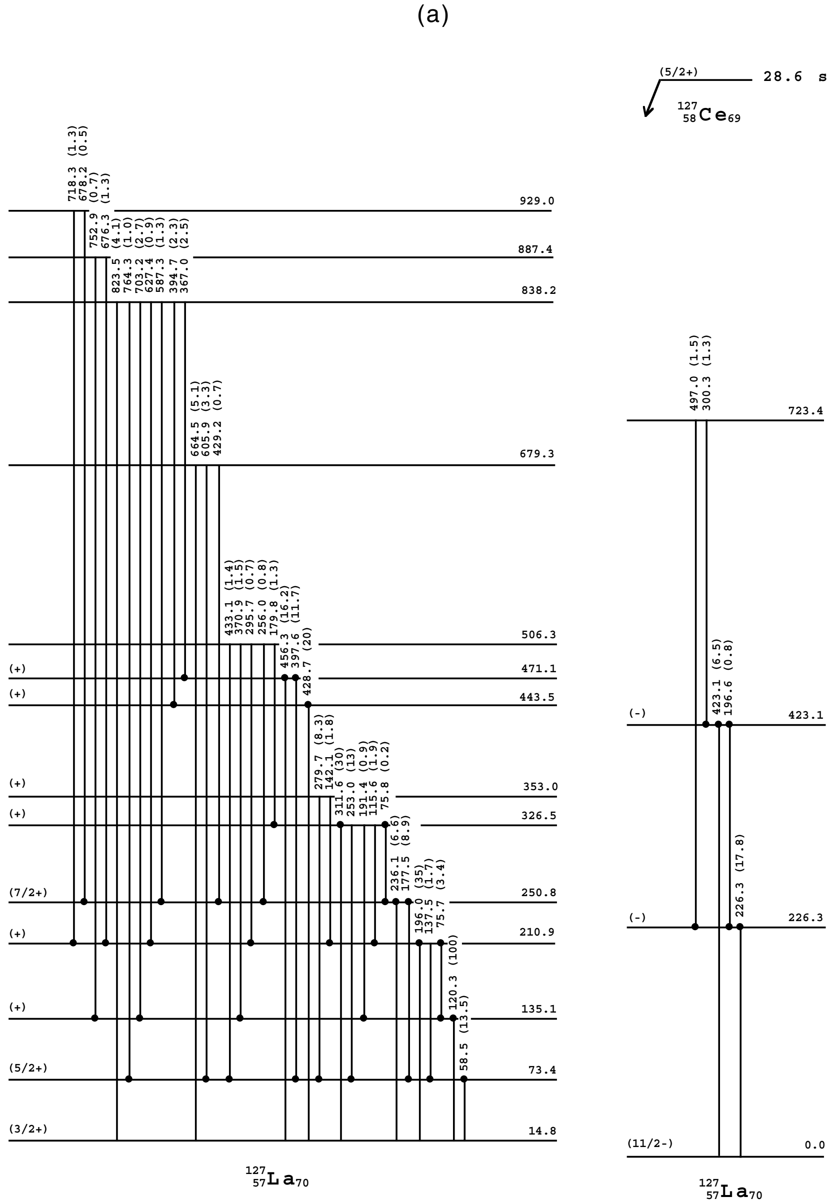

Fig. 3. Level scheme of ^{127}La fed in the β^+/EC decay of ^{127}Ce.

γ-rays are not in agreement from the two experiments. This discrepancy may partly be attributed to feeding by the (34 ± 2) s isomer in ^{127}Ce.

Conversion coefficients for some intense transitions in the decay of ^{127}Ce are listed in table 2. They were calculated relative to the K conversion coefficient for the 229.9-keV transition $(2_1{}^+ \rightarrow 0_1{}^+)$ in ^{124}Ba. The conversion electron intensities used to derive the conversion coefficients were determined using the efficiency curve of the Si(Li) detector obtained from a calibration with ^{133}Ba and ^{207}Bi conversion electron sources. The total conversion coefficient of the 58.5-keV transition was deduced from the intensity balance between this transition and the 397.6-keV transition by using the cascade relation between these transitions. Here the intensities of these γ-rays were obtained from the spectrum gated on the 367.0-keV γ-ray, and the multipolarity of the 397.6-keV transition was assumed to be $M1$ or $E2$. As seen in table 2, all of the conversion coefficients we have measured are consistent with $M1$ and/or $E2$ multipolarity.

The strong 196.0-keV γ-ray was found to be delayed as seen in fig. 2. From the slope of the curve, and taking into consideration the time resolution of about 4 ns, the half-life was deduced to be (1.9 ± 0.3) ns. No other strong γ-rays were observed to be delayed, and thus the half-life can be ascribed to the 210.9-keV level.

4 Level scheme

A level scheme of ^{127}La constructed from the present measurements is shown in fig. 3. Although most of observed

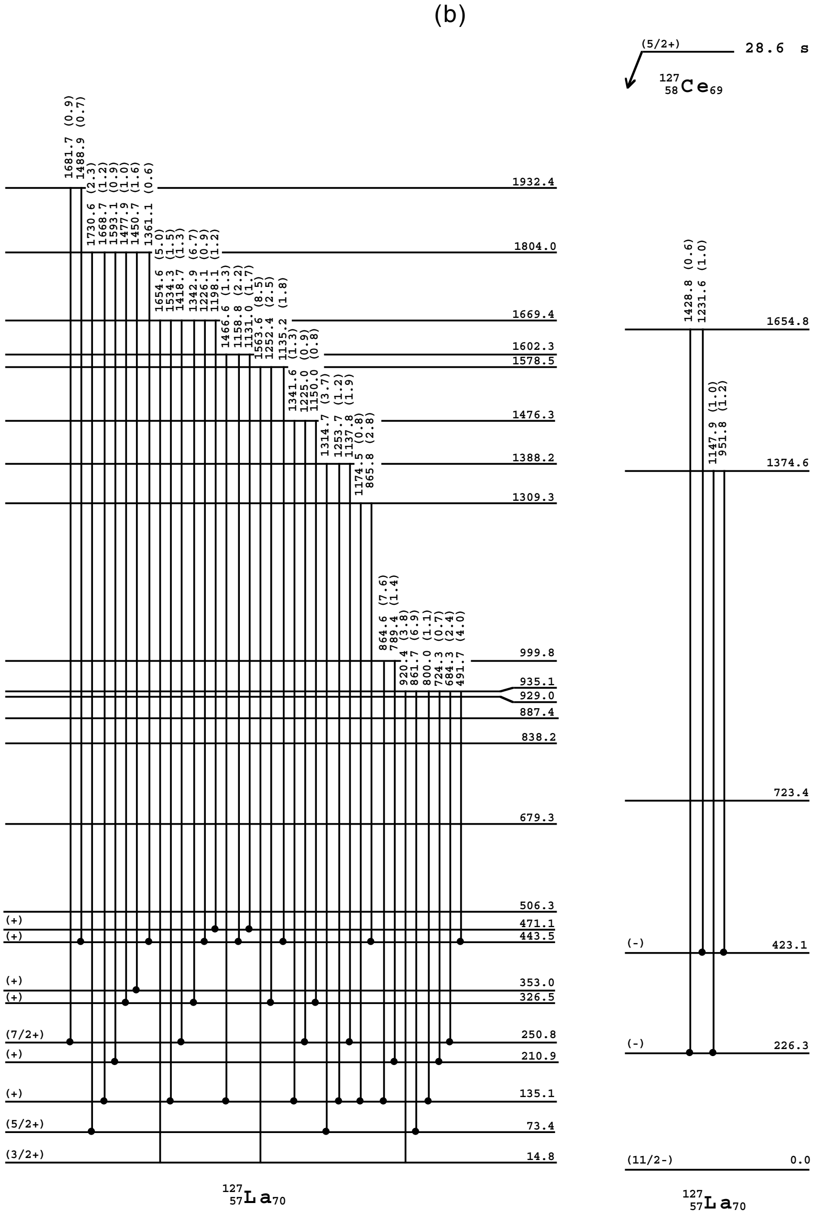

Fig. 3. Continued.

γ-rays were incorporated into the level scheme, γ-rays of 103.2, 176.4, 631.2, 1071.9, 1148.2, 1838.2, and 1961.1 keV were not placed in it. Energy levels that we observed up through the 471.1-keV level are in general agreement with those of Genevey *et al.* [7]. However a new level at 423.1 keV was introduced, and three previously reported levels at 215.9, 386.5, and 424.0 keV were not confirmed by the present measurements. Above the 471.1-keV level, only the levels at 838.2, 929.0, 935.1, and 999.8 keV were reported earlier [7].

As seen in fig. 3, the proposed level scheme shows two different sets of levels with no interconnections. One contains the lower members of the $3/2^+$ band observed in in-beam studies [2–4]. An excitation energy of 14.8 keV for the $3/2^+$ level is taken from ref. [12], which calculated the value from γ-ray energies found in ref. [2]. We could not confirm this value in this experiment. The levels at 73.4 and 250.8 keV correspond to the $5/2^+$ and $7/2^+$ members of this band, respectively. The other set is assumed to be based on the ground state.

According to ref. [12], the spin-parities of the ground state, 14.8-, 73.4-, and 250.8-keV levels are $(11/2^-)$, $(3/2^+)$, $(5/2^+)$, and $(7/2^+)$, respectively. The assignments for the ground state and the 14.8-keV level are from the level systematics of odd-mass La nuclides, and those for the other levels are from ref. [2], which is based on a cranked shell-model analysis of the experimental results. Later Starosta *et al.* [3] measured angular correlations and linear polarizations of γ-rays using an in-beam method, and obtained consistent results with these assignments. From the multipolarities of transitions assigned in this experiment, the 73.4-, 135.1-, 210.9-, 250.8-, 326.5-, 353.0-, 443.5-, and 471.1-keV levels were determined to be the same parity states as the 14.8-keV level, while the 226.3- and 423.1-keV levels have the same parity as the ground state. These results are in agreement with the results of in-beam studies [2,3] for the 73.4- and 250.8-keV levels, and also with the results of an independent β-decay study [7] for all the levels, except the newly introduced 423.1-keV level.

Two different half-lives were reported in the β-decay of ^{127}La [12]: one of 5.1 min determined by γ-ray measurements [9,13,14] and another one of 3.7 min by β-ray measurements [15,16]. The half-life of 5.1 min was assigned to the β-decay of the $11/2^-$ ground state in ^{127}La [14], because levels at relatively high spins in ^{127}Ba are fed in this decay. This assignment is the same as in ref. [17]. Meanwhile the half-life of 3.7 min was preliminarily assigned to the decay of the $3/2^+$ level at 14.8-keV in ^{127}La [12]. In the present work ^{127}Ce and ^{127}La samples were simultaneously collected, and the four strongest γ-transitions in ^{127}Ba at 56.2 keV ($3/2^+ \to 1/2^+$), 79.4 keV ($(9/2^-) \to 7/2^-$), 114.3 keV ($(7/2^+) \to (5/2^+)$), and 134.3 keV ($(11/2^-) \to (9/2^-)$), where the assignments are taken from ref. [12], were successively counted. It was found that the time decay curves for these γ-rays exhibited, in the same manner, a feeding of the ^{127}Ce β-decay. This is surprising because the $3/2^+$ level at 14.8-keV in ^{127}La is predominantly populated in the β-decay of ^{127}Ce as seen in fig. 3 and should decay to low-spin states in ^{127}Ba. Among these four γ-rays, only the 56.2-keV γ-ray was assumed to belong to the β-decay of the 14.8-keV state [12]. Meanwhile these four γ-rays are the strongest ones following the β-decay of the ground state in ^{127}La [14]. From the fact that the time decay curves not only for the 56.2-keV γ-ray but for the other three γ-rays exhibited a feeding of the ^{127}Ce β-decay, one expects that the 14.8-keV state decays mainly to the ground state in ^{127}La. However, this is inconsistent with the Weisskopf single-particle estimate for the half-life, 30 y of a $M4$ isomeric transition from the $3/2^+$ state to the $11/2^-$ ground state. This puzzle could not be resolved from the present studies, and the decay pattern of the 14.8-keV state remains unclear.

Because the β-decay branchings to the ground and 14.8-keV states in ^{127}La are unknown, log ft values for the ^{127}La states fed from ^{127}Ce decay can not be calculated. However, by assuming those two branchings to be 0%, one estimates that the $5/2^+$ state at 73.4 keV has an (EC+β^+) feeding of approximately 17%. For ^{127}Ce three intrinsic states of $1/2^+$, $5/2^+$, and $7/2^-$ have been suggested from in-beam studies [18] and the β-decay of ^{127}Pr [19]. The excitation energies of these states are unknown [18,19], but are expected to be very low from the systematics in the odd-mass Ce nuclei. From the (EC + β^+) feeding to the $5/2^+$ state in ^{127}La, it is likely that the only observed β-decaying level of ^{127}Ce has $I^\pi = 5/2^+$.

5 Discussion

Based on in-beam studies Ward *et al.* [2] proposed that the 14.8-keV state was the band head of the Nilsson orbital of [422]↓, and the 73.4- and 250.8-keV states are rotational band members. They also assigned the band head of the [404]↑ orbital to the level at 610.6 keV [2]. In the present work, we performed theoretical calculations based on the Nilsson model in which pair correlation, quasiparticle-phonon interaction, rotation-vibration interaction and Coriolis coupling were taken into consideration. Details of the model are described in ref. [20]. The Nilsson potential parameters, $\kappa = 0.065$ and $\mu = 0.57$ were used according to ref. [21]. The quadrupole deformation parameter was deduced to be $\beta = 0.24$ from the measured life-time of the 250.8-keV state and the $E2/M1$ mixing ratio for the 177.5-keV transition [22]. Calculations with the folded Yukawa potential give a similar prediction, $\varepsilon = 0.252$ [23]. The hexadecapole deformation was not included. The rotational parameter $\hbar^2/2\mathcal{J}$ was adjusted to reproduce the experimental levels of the [422]↓ band. As a result, $\hbar^2/2\mathcal{J} = 20.0$ keV was obtained. A BCS calculation was performed with the pairing coupling constant $G = 20.8/A$ MeV [24]. Vibration energies were chosen as $E_\beta = 898$ keV and $E_\gamma = 873$ keV which reproduce the energies of the second 0^+ and 2^+ states in ^{124}Ba ($Z = 56$) [25], respectively.

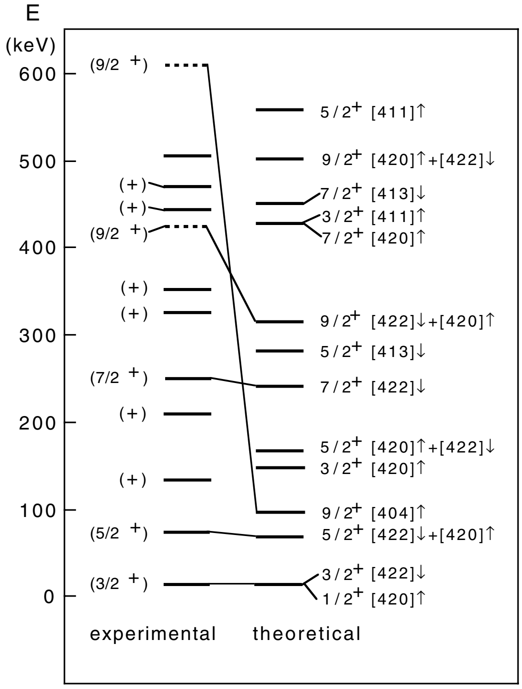

Fig. 4. Experimental and theoretical positive-parity level schemes of ^{127}La. Theoretical calculations are based on the Nilsson model. The levels observed by in-beam spectroscopy [2,3] are indicated by dashed lines.

The calculated levels are compared to the experimental ones in fig. 4. The band head of the [422]↓ orbital, found at lowest energy in the experiment, also appears at the lowest energy in the calculated spectrum. The other lowest band calculated is [420]↑, and these two bands are rather strongly mixed. Genevey *et al.* [7] made an IBFM calculation, and showed that the lowest calculated positive-parity state is $3/2^+$ and that a $1/2^+$ state is located slightly above the $3/2^+$ state. These calculated results are the same as ours as seen in fig. 4, which only shows the calculated levels from the present work. For the [420]↑ band, it is difficult to assign the calculated levels to the experimental ones because spins of many levels remain undetermined. However, by considering the level energies and decay patterns it is likely that the experimental levels at 135.1 and 210.9 keV are the $1/2^+$ and $5/2^+$ members of this band, respectively.

To examine these assignments transition probabilities of γ-transitions depopulating these levels were calculated by using the values of $g_l = 1$, $g_s = 0.5g_s$(free), $g_R = Z/A$, and $e_p = 2.0e$. As a result, the theoretical branching ratio was obtained to be $I_\gamma(135.1\,\text{keV} \rightarrow 73.4\,\text{keV})/I_\gamma(135.1\,\text{keV} \rightarrow 14.8\,\text{keV}) = 0.4$. The γ-transition from the 135.1-keV level to 73.4-keV level was not observed experimentally. This experimental result does not agree with the calculation, but the latter still reproduces qualitatively the relatively strong 120.3-keV transition. In addition, the results of the calculations gives theoretical partial γ half-lives, 0.72, 0.72, and 110 ns for the 196.0-, 137.5-, and 75.7-keV γ-transitions, respectively, which are depopulating the 210.9-keV level. The experimental values are $T_{1/2}(196.0\,\text{keV}) = (3.3\pm0.8)$ ns, $T_{1/2}(137.5\,\text{keV}) = (68\pm16)$ ns, and $T_{1/2}(75.7\,\text{keV}) = (34\pm8)$ ns from the half-life of the 210.9-keV level obtained in the present work. As for the 196.0- and 75.7-keV transitions, the calculated values are consistent with the experimental ones.

As seen in the above discussion, some experimental data for ^{127}La is qualitatively reproduced by the Nilsson model. However, overall agreement between the theoretical and experimental results was not obtained, and further studies both in experiments and theories are expected.

We wish to thank the crew of the JAERI tandem accelerator for providing the beams.

References

1. P.J. Smith, D.J. Unwin, A. Kirwan, D.J.G. Love, A.H. Nelson, P.J. Nolan, D.M. Todd, P.J. Twin, J. Phys. G **11**, 1271 (1985).
2. D. Ward, V.P. Janzen, H.R. Andrews, S.M. Mullins, D.C. Radford, J.C. Waddington, *Proceedings of the International Conference on Nuclear Physics in Our Times, Sanibel, 1992* (World Scientific, 1993) p. 218.
3. K. Starosta, Ch. Droste, T. Morek, J. Srebrny, D.B. Fossan, D.R. LaFosse, H. Schnare, I. Thorslund, P. Vaska, M.P. Waring, W. Satuła, S.G. Rohoziński, R. Wyss, I.M. Hibbert, R. Wadsworth, K. Hauschild, C.W. Beausang, S.A. Forbes, P.J. Nolan, E.S. Paul, Phys. Rev. C **53**, 137 (1996).
4. C.M. Parry, R. Wadsworth, A.N. Wilson, A.J. Boston, P.J. Nolan, E.S. Paul, J.A. Sampson, A.T. Semple, C. Foin, J. Genevey, A. Gizon, J. Gizon, I. Ragnarsson, B.G. Dong, Phys. Rev. C **61**, 021303 (2000).
5. D.D. Bogdanov, A.V. Demyanov, V.A. Karnaukhov, M. Nowicki, L.A. Petrov, J. Voboril, A. Plochocki, Nucl. Phys. A **307**, 421 (1978).
6. J. Genevey, A. Gizon, N. Idrissi, B. Weiss, R. Béraud, A. Charvet, R. Duffait, A. Emsallem, M. Meyer, T. Ollivier, N. Redon, *Proceedings of the 5th International Conference on Nuclei Far From Stability, Rosseau Lake, 1987*, AIP Conf. Proc. **164**, 419 (1988).
7. J. Genevey, A. Gizon, D. Barnéoud, Gh. Cata-Danil, R. Béraud, A. Emsallem, C. Foin, C.F. Liang, P. Paris, S. Viteritti, Z. Phys. A **356**, 7 (1996).
8. H. Iimura, S. Ichikawa, M. Oshima, J. Katakura, N. Shinohara, M. Magara, A. Osa, T. Tamura, M. Asai, H. Yamamoto, in *Proceedings of the 9th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics, Budapest, 1996* (Springer, 1997) p. 297.
9. S. Ichikawa, T. Sekine, M. Oshima, H. Iimura, Y. Nakahara, Nucl. Instrum. Methods Phys. Res. B **70**, 93 (1992).
10. S. Ichikawa, T. Sekine, H. Iimura, M. Oshima, N. Takahashi, Nucl. Instrum. Methods Phys. Res. A **274**, 259 (1989).
11. R.S. Hager, E.C. Seltzer, Nucl. Data A **4**, 1 (1968).
12. K. Kitao, M. Oshima, Nucl. Data Sheets **77**, 1 (1996).
13. J.R. Leigh, K. Nakai, K.H. Maier, F. Puhlhofer, F.S. Stephens, R.M. Diamond, Nucl. Phys. A **213**, 1 (1973).
14. M. Miyaji, master degree thesis, Nagoya University, 1989.
15. I.L. Preiss, P.M. Strudler, R. Wolfgang, Phys. Rev. **129**, 1284 (1963).
16. L. Yaffe, J.M. Alexander, E.K. Hyde, Can. J. Chem. **41**, 1951 (1963).
17. A. Gizon, *Proceedings of XXV Zakopane School on Physics, Zakopane, Poland, 1990, Selected Topics in Nuclear Structure*, Vol. **2** (World Scientific, Singapore, 1990) p. 93.
18. B.M. Nyakó, J. Gizon, V. Barci, A. Gizon, S. André, D. Barnéoud, D. Curien, J. Genevey, J.C. Merdinger, Z. Phys. A **334**, 513 (1989).
19. J. Gizon, J. Genevey, D. Barnéoud, A. Astier, R. Béraud, Gh. Cata-Danil, A. Emasallem, J. Gizon, Y. Le Coz, C.F. Liang, P. Paris, Z. Phys. A **351**, 361 (1995).
20. F. Weller, Fortschr. Phys. **19**, 201 (1971).
21. T. Bengtsson, I. Ragnarsson, Nucl. Phys. A **436**, 14 (1985).
22. K. Starosta, Ch. Droste, T. Morek, J. Srebrny, D.B. Fossan, S. Gundel, J.M. Sears, I. Thorslund, P. Vaska, M.P. Waring, S.G. Rohoziński, W. Satuła, U. Garg, S. Nauguleswaran, J.C. Walpe, Phys. Rev. C **55**, 2794 (1997).
23. G.A. Leander, P. Möller, Phys. Lett. B **110**, 17 (1982).
24. C. Gustafson, I.L. Lamm, B. Nilsson, S.G. Nilsson, Ark. Fys. **36**, 613 (1967).
25. N. Idrissi, A. Gizon, J. Genevey, P. Paris, V. Barci, D. Barnéoud, J. Blachot, D. Bucurescu, R. Duffait, J. Gizon, C.F. Liang, B. Weiss, Z. Phys. A **341**, 427 (1992).