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Study of parity-doublet structure in the ^{147}La nucleus

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Abstract.
The work reports several new excited states in the neutron-rich ^{147}La nucleus, populated in spontaneous fission of ^{252}Cf. The excitation scheme has been reinvestigated by means of γ-ray spectroscopy, using high-fold γ coincidences measured with the Gammasphere array of Ge detectors. It is shown that the 229.65-keV level has spin and parity $11/2^-$, which changes the $9/2^-$ spin-parity reported in a recent evaluation and sets up the spin-parity of the ground state as $5/2^+$. New levels allow to arrange the excitation scheme of ^{147}La into a parity-doublet-like structure showing that the ^{147}La nucleus may have an octupole deformation.

1 Introduction

The region of neutron-rich nuclei with masses A≈150 is a place where octupole correlations can be studied in detail. The presence of strong octupole correlations in this region has been predicted [1]. Results suggested the presence of stable octupole deformation in the ^{146}Ba nucleus which was supported experimentally later [2]. leaving, however, some open questions. In octupole deformed nuclei one would expect enhanced E1 transitions but in ^{146}Ba those transitions are weak. This kind of behavior has been explained by further developments in theory as particular canceling of the E1 strength at the neutron number N=90 [3], while reproducing strong E1 decays observed in the ^{144}Ba neighbor [4] at N=88. The present status based on studies of of ^{144}Ba [4, 5] is that there is an octupole deformation in Ba isotopes.

It is interesting to ask about the presence of octupole correlations in odd-A neighbors of even-even nuclei possessing stable octupole deformation. Such correlations should alter positions of single-particle orbital as seen e.g. in the ^{147}Ba nucleus. Theoretical calculations predicted spin and parity $3/2^-$ for its ground state [1] but experimental results are pointing to $5/2^-$ value and the low-spin structure is assigned to a reflection-symmetric shape [6]. Similar behavior is observed in ^{145}Ba [7]. This raises questions about the presence of octupole deformation in odd-A, Ba isotopes and the mechanism of weakening of octupole correlations in these nuclei.

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One may search for parity doublets in odd-Z nuclei to probe the strength of octupole effects in the region. Parity-doublet bands have been proposed in ^{151}Pm [8, 9] and ^{153}Eu [10], N=90 isotones. In the N=90 isotone ^{147}La, excited states could be arranged into a parity-doublet structure, though only at higher excitation energy [11, 12]. In both works spin and parity $11/2^-$ were assigned to the 229.65-keV level, therefore it was a surprise that the recent compilation [13] has reported $9/2^-$ spin-parity for this level. Such an assignment does not agree with the proposed parity doublet structure in ^{147}La. Moreover, recent works report the presence of $11/2^-$ bands in other N=90 isotones, ^{145}Cs [14] and ^{149}Pr [15]. In the present work the excitation scheme of ^{147}La was reinvestigated, using higher-statistics data, as compared to previous studies. The aim was to confirm the presence of parity doublet bands by verifying spins and parities of excited states.

2 Reinvestigation of ^{147}La

The presented data results from a measurement of γ-rays emitted in spontaneous fission of ^{252}Cf. γ-rays were registered with the Gammasphere array of Anti-Compton Spectrometers (ACS) [16]. Prompt γ-rays emitted in fission were analyzed using triple-γ coincidence matrices. This technique was described in a number of previous papers (see e.g. Refs.[17–19]). The sum of γ spectra, gated on the yrast cascade of ^{147}La is presented in Fig. 1. This is similar to the spectrum shown in Ref. [12], but now the statistics is about 20 times higher.

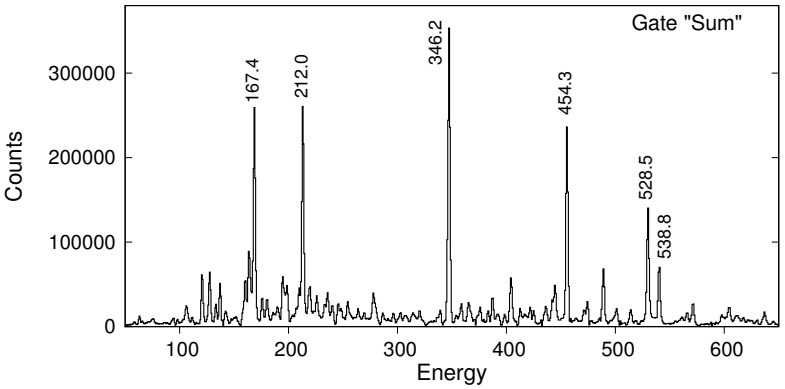

Figure 1. Sum of γ-ray spectra doubly gated in a triple-γ histogram on pairs of lines from the 167.6-212.0-346.3-454.4-528.5-keV, yrast cascade in ^{147}La, as obtained in this work.

In this work we confirm major coincidence relations and the arrangement of excited levels into bands in ^{147}La, as reported in previous works [11, 12]. Moreover, in the low-spin part, we observe a number of important transitions, which allow to arrange excited levels and transitions in ^{147}La into a parity-doublet structure similar to the structure observed in ^{151}Pm. In Fig. 2 we present the new excitation scheme of ^{147}La. New lines are marked with asterisks. Strong in-band E2, stretched transitions with simplex value $s = +i$ can be seen in Fig. 1. In the excitation scheme we omitted transitions and levels populated in β decay of ^{147}Ba [20] presented in a previous work [12].

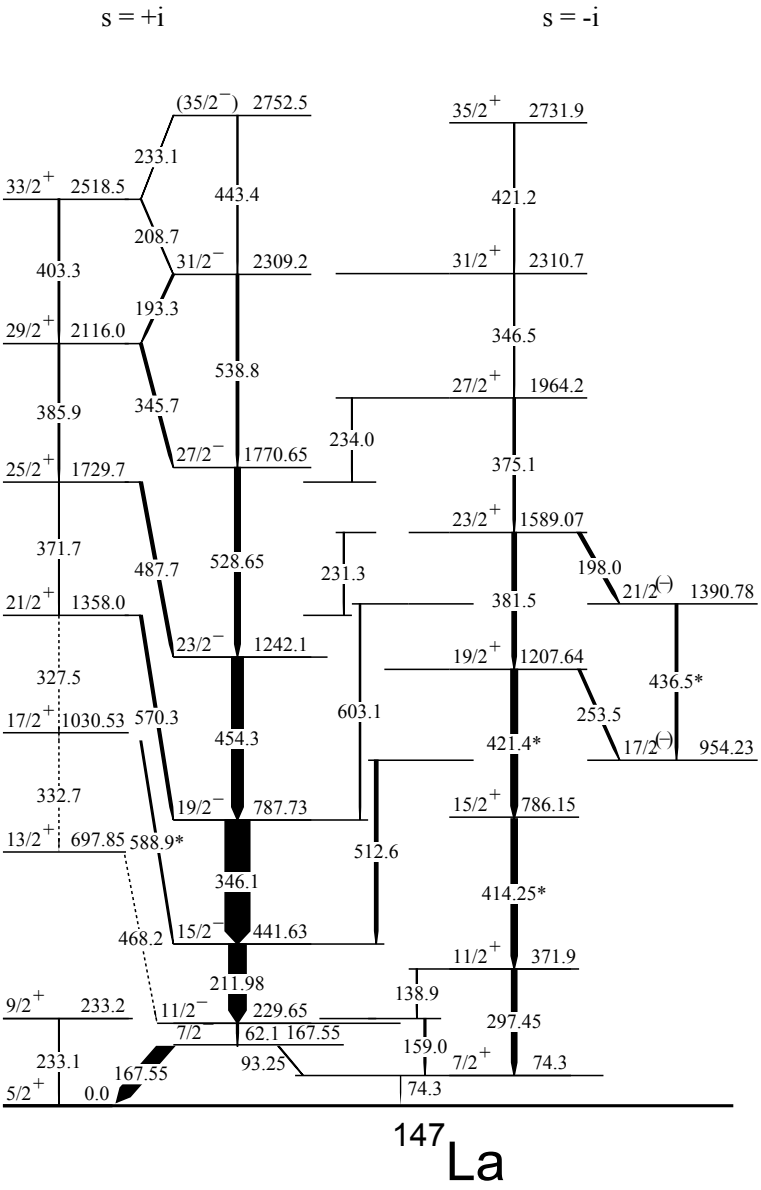

Figure 2. Scheme of excited levels in ^{147}La, populated in spontaneous fission of ^{252}Cf, as observed in the present work. The thickness of the arrows is proportional to their relative γ intensities. New lines are marked with asterisks. See text for further information.

Figure 3 shows a γ-ray spectrum cut from a 3D histogram containing prompt triple-γ coincidences, sorted within a time window of 600 ns. The spectrum is obtained by gating on the known 167.55–211.98-keV lines. In the spectrum one can see prompt-γ 487.7-, 528.65-, 538.8-, 570.3-, 588.9-keV lines in band corresponding to the simplex value $s = +i$. In addition one observes two new transitions of energies 512.6- and 603.1-keV, marked with asterisks.

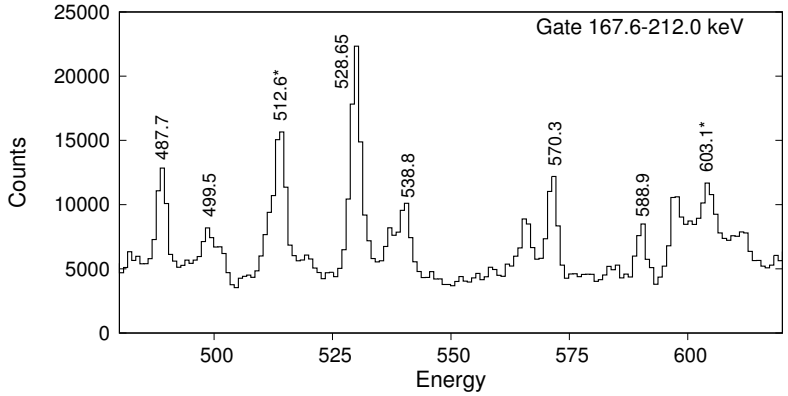

Figure 3. γ-ray spectrum doubly gated on the 167.55- and 212.0-keV lines in ^{252}Cf fission data. Energies are given in keV. New lines are marked with asterisks.

Spectra obtained by gating on the known 211.98-keV transition and new 512.6- and 603.1-keV transitions, respectively are shown on Figs. 4 and 5. Next to the 167.55-, 346.1- and 375.1-keV lines, reported earlier [11, 12], there are new lines at 198.0, 253.5, 381.5 and 436.5 keV. This and other gated spectra allow to assign these transitions to the $s = -i$ branch of the parity doublet.

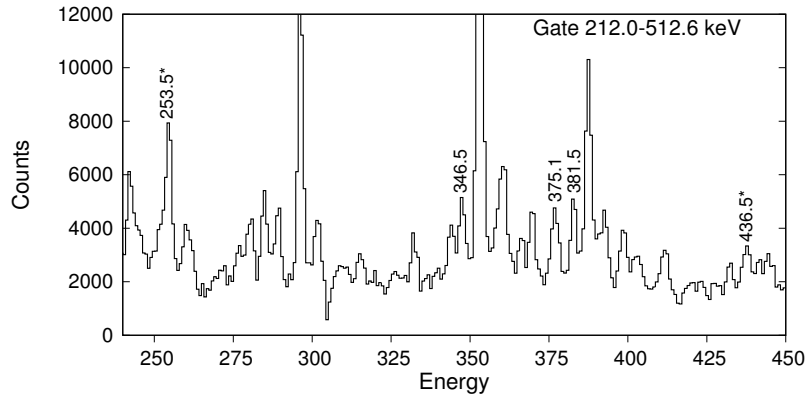

Figure 4. γ-ray spectrum doubly gated on 212.0- and 512.6-keV lines in the ^{252}Cf fission data. Energies are given in keV. New lines are marked with asterisks.

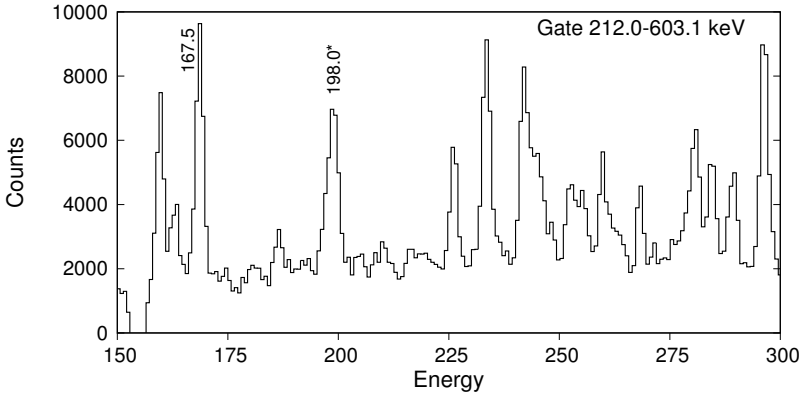

Figure 5. γ-ray spectrum doubly gated on 212.0- and 603.1-keV lines in the ^{252}Cf fission data. Energies are given in keV. New lines are marked with asterisks.

A γ-ray spectrum, doubly gated on the 297.45- and 381.5-keV new lines of ^{147}La, is presented in Fig. 6. One can see the 346.5- and 375.1-keV lines reported previously as well as two new lines at 414.25 and 421.4 keV. Analysis of other doubly-gated spectra lead us to the conclusion that these two transitions connect the 1207.64- and 371.9-keV levels via new 786.15-keV level. We propose the ordering of the two new lines as presented in Fig. 2.

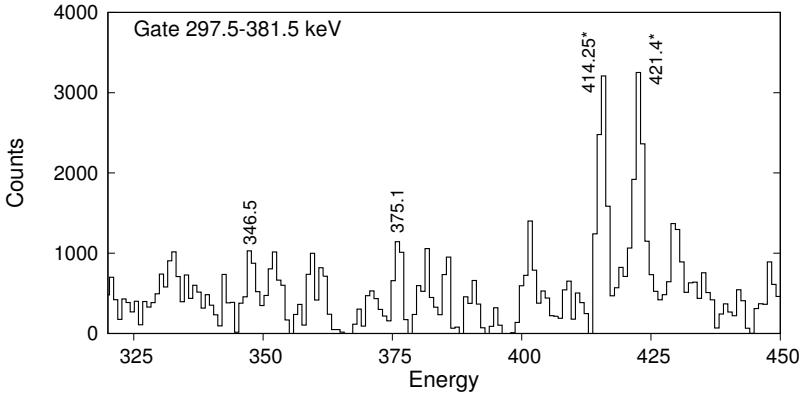

Figure 6. γ-ray spectrum doubly gated on 297.5- and 381.5-keV lines in the ^{252}Cf fission data. Energies are given in keV. New lines are marked with asterisks.

Spins and parities of levels shown in Fig. 2 have been, generally, adopted from Refs. [11, 12], but some values have been altered and some are new. In order to determine new spins and parities we analyzed angular correlations for cascades of γ rays in ^{147}La populated in spontaneous fission of ^{252}Cf. Characteristic, pure quadrupole-quadrupole (Q-Q) and pure dipole quadrupole (D-Q) angular correlations are shown in figure 7. The $\gamma\gamma$ angular correlations in the 346.1-211.98-keV and 454.3-346.1-keV cascades are consistent with a stretched quadrupole nature of these transitions.

Spin assignments to higher energy levels in this band are proposed based on the assumption of a stretched E2 character for the transitions between those levels and the fact that spins are growing with excitation energy, as commonly observed for excited states populated in spontaneous fission [21].

Angular correlation data are also consistent with the dipole character of the 570.3- and 588.9-keV transitions and therefore they are in-band transitions connecting states, which differ by one unit of angular momentum and have opposite parity. Angular correlations for the 371.7-570.3-keV $\gamma\gamma$ cascade shows that the 371.7-keV transition may be a quadrupole transition. Therefore we propose that the yrast band above the 1358.0-keV level consists of stretched E2 transitions connecting levels in a positive-parity band. The mixing ratios, $\delta = 0.030^{+38}_{-37}$ and -0.021^{+24}_{-26} for the 603.1- and 512.6-keV transitions respectively indicate a pure M1 multipolarity for both transition. This provides negative parity assignments for the 954.23- and 1390.78-keV levels.

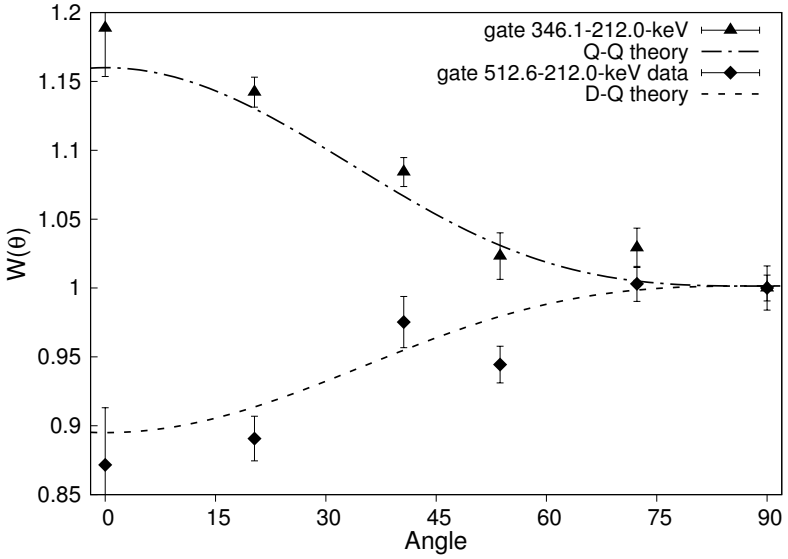

Figure 7. Example of angular correlations in ^{147}La for Quadrupole-Quadrupole and Dipole-Quadrupole cascades, as measured in this work. See text for further information.

To establish spin and parity of the 229.65-keV level we have determined the conversion coefficient for the 62.1-keV transition. By setting a double gate on the 346.1- and 167.55-keV transitions we obtain a spectrum in which the 211.98- and 62.1-keV transitions have the same total intensity. We have established earlier by using angular correlations that the 211.98-keV transition is pure E2. Taking the theoretical $\alpha_{tot}(211.98) = 0.1463$ value we calculated the total intensity in this gate and then used it to calculate the total conversion coefficient for the 62.1-keV transition. The obtained value of $\alpha_{tot}(62.1) = 11.8(1.5)$ is consistent with a pure E2 transition, considering the theoretical value of $\alpha_{tot} = 11.29$ for a pure E2 transition. We adopt spin-parity $5/2^+$ and $7/2^-$ for the ground state and the 167.55-keV level, respectively. These assignments were made by confirming the stretched E1 character of the 167.55-keV transition and the β-decay properties of the ground state of ^{147}Ba. Therefore we propose the 229.65-keV level to have spin and parity $11/2^-$. This is in agreement with

the previous findings [11, 12] and changes the value $9/2^-$, reported in the evaluation of the data for ^{147}La [13].

References

[1] G. A. Leander, W. Nazarewicz, P. Olanders, I. Ragnarsson, and J. Dudek, Phys. Lett.**152B**, 284 (1985).

[2] W. R. Phillips, I. Ahmad, H. Emling, R. Holzmann, R. V. F. Janssens, T.-L. Khoo, and M. W. Drigert, Phys. Rev. Lett.**57**, 3257 (1986).

[3] W.Nazarewicz, Proc. Int. Conf. "Nuclear Structure in the Nineties", Oak Ridge 1990, ed. N.R. Johnson, Nucl. Phys. A **520** 333c, (1990).

[4] W. Urban, M. A. Jones, J. L. Durell, M. J. Leddy, W. R. Phillips, A. G. Smith, B. J. Varley, I. Ahmad, L. R. Morss, M. Bentaleb, E. Lubkiewicz, and N. Schulz, Nucl. Phys. **A613**, 107 (1997).

[5] B. Bucher, S. Zhu, C.Y. Wu, R.V.F. Janssens, D. Cline, A.B. hayes, M. Albers, A.D. Ayangeakaa, *et al.*, Phys. Rev. Lett. **116**, 112503 (2016).

[6] T. Rząca-Urban, W. Urban, A. G. Smith, I. Ahmad, A. Symtfeld-Każuch, Phys. Rev. C **87**, 031305(R) (2013).

[7] T. Rząca-Urban, W. Urban, J. A. Pinston, A. G. Smith, I. Ahmad, Phys. Rev. C **83**, 067301 (2011).

[8] W. Urban, J. C. Bacelar, W. Gast, G. Hebbinghaus, A. Krämer-Flecken, R. M. Lieder, T. Morek, T. Rząca-Urban, Phys. Lett. B247, 238 (1990).

[9] W. J. Vermeer, M. K. Khan, A. S. Mowbray, J. B. Fitzgerald, J. A. Cizewski, B. J. Varley, J. L. Durell, and W. R. Phillips Phys.Rev. C **42**, R1183 (1990).

[10] C.J. Pearson, W. R. Phillips, J. L. Durell, B. J. Varley, W. J. Vermeer, W. Urban, and M. K. Khan Phys. Rev. C **49**, R1239 (1994).

[11] W. Urban, W. R. Phillips, J. L. Durell, M. A. Jones, M. J. Leddy, C. J. Pearson, A. G. Smith, B. J. Varley, Phys. Rev. C **54**, 945 (1996).

[12] S. J. Zhu, J. H. Hamilton, A. V. Ramayya, M. G. Wang, J. K. Hwang, E. F. Jones, L.K. Peker, B.R.S. Babu, G. Drafta, W.C. Ma, G.L. Long, *et al.*, Phys. Rev. C **59**, 1316 (1999).

[13] N. Nica, Nucl. Data Sheets **110**, 749 (2008).

[14] T. Rząca-Urban, W. Urban, J. A. Pinston, G. S. Simpson, J. L. Durell, A. G. Smith, I. Ahmad, Phys. Rev. C **82**, 017301 (2010).

[15] T. Rząca-Urban, W. Urban, J. A. Pinston, G. S. Simpson, A. G. Smith, J. F. Smith, I. Ahmad, Phys. Rev. C **82**, 067304 (2010).

[16] D. Patel, A.G. Smith, G.S. Simpson, R.M. Wall, J.F. Smith, O.J. Onakanmi, I. Ahmad, J.P. Greene, M.P. Carpenter, T. Lauritsen, C.J. Lister, R.F. Janssens, F.G. Kondev, D. Seweryniak, B.J.P. Gall, O. Dorveaux, B. Roux, J. Phys. G. Nucl. Part. Phys. 28. 649 (2002).

[17] W. Urban, W. Kurcewicz, A. Nowak, T. Rząca-Urban, J. L. Durell, M. J. Leddy, M. A. Jones, W. R. Phillips, A. G. Smith, *et al.*, Eur. Phys. J. A **5**, 239 (1999).

[18] W. Urban, J.L. Durell, W.R. Phillips, A.G. Smith, M.A. Jones, I. Ahmad, A.R. Barnet, S.J. Dorning, M.J. Leddy, E. Lubkiewicz, L.R. Morss, T. Rząca-Urban, R.A. Sareen, N. Schulz, B.J. Varley, Z. Phys. A **358**, 145 (1997).

[19] M.A. Jones, W. Urban, W.R. Phillips, Rev. Sci. Intrum. 4120, **136** (1998)

[20] M. Shmid, Y. Y. Chu, G. M. Gowdy, R. L. Gill, H. I. Liou, M. L. Stelts, R. E. Chrien, R. F. Petry, H. Dejbakhsh, C. Chung, D. S. Brenner, Proc. Int. Conf. Nuclei Far from Stability (1981)

[21] I.Ahmad, W.R.Phillips, Rep. Prog. Phys. **58**, 1415 (1995).