Near-yrast, medium-spin structure of ^{143}Xe

T. Rząca-Urban,[1] W. Urban,[1,2] J. A. Pinston,[3] A. G. Smith,[4] and I. Ahmad[5]
[1]*Faculty of Physics, University of Warsaw, ulica Hoża 69, PL-00-681 Warsaw, Poland*
[2]*Institut Laue-Langevin, 6 rue J. Horowitz, F-38042 Grenoble Cedex 9, France*
[3]*Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier Grenoble 1, CNRS/IN2P3, Institut National Polytechnique de Grenoble, F-38026 Grenoble Cedex, France*
[4]*School of Physics and Astronomy, The University of Manchester, Manchester M13 9PL, United Kingdom*
[5]*Argonne National Laboratory, Argonne, Illinois 60439, USA*
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Excited states in ^{143}Xe, populated in spontaneous fission of ^{248}Cm, are studied by means of γ spectroscopy using the EUROGAM 2 Ge array. We identify three rotational bands in ^{143}X: a decoupled band originating from the $i_{13/2}$ neutron excitation, a strongly coupled band based on the $5/2^-$ ground state, and a decoupled band based on the 322.9-keV level with spin 9/2. The new excitation scheme of ^{143}Xe is compared to quasiparticle-rotor model calculations, performed with a reflection-symmetric potential.

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The $5/2^-$ spin and parity of the ground state in ^{143}Xe is well established [1] and together with the $3/2^+$ ground state in ^{143}Cs it can explain the 1^- and 4^- spin and parity of the ground state and the 92.2-keV isomer in ^{144}Cs, respectively [2]. However, the neutron configuration corresponding to this state is a puzzle. One would expect, for the ground state of ^{143}Xe, spin and parity of $1/2^+$ or $3/2^-$, corresponding to the 1/2[660] or 3/2[521] orbitals, respectively (see Fig. 2 in Ref. [3]). The fact that it is $5/2^-$ suggests that the Nilsson scheme may not be valid in ^{143}Xe because of too low a deformation. (We note that the ground state of ^{141}Xe also has spin and parity $5/2^-$.) Alternatively, it is possible that the deformation of ^{143}Xe is not too low but that octupole correlations present in this region [4–7] change the order of the Nilsson orbitals, as proposed by Leander *et al.* [3].

In ^{143}Xe one might expect a deformed band based on the ground state (g.s.), by analogy with the g.s. band observed in the ^{145}Ba isotope [5]. Observation of such a band in ^{143}Xe should help to identify the ground-state configuration. By analogy with ^{145}Ba, one may also expect a low-lying $13/2^+$ level (in ^{143}Xe) originating from the $\nu i_{13/2}$ orbital, with a rotational band on top of it. The properties of rotational bands in ^{143}Xe should allow the deformation to be determined and the validity of the Nilsson scheme for this nucleus to be verified. The study of the evolution of the deformation along the $N = 89$ isotonic chain should also help predict the properties of excited states in $N = 89$ isotones with $Z < 54$, ^{141}Te and ^{139}Sn.

Excited levels in ^{143}Xe were identified and studied by Bentaleb *et al.* [8] in a measurement of prompt γ rays following spontaneous fission of ^{248}Cm using the EUROGAM 1 detector array. In Ref. [8], a band was found on top of the 741.0-keV level that resembles the $13/2^+$ band in ^{145}Ba but has a different decay pattern. The limited information reported in Ref. [8] is not sufficient to provide a reliable interpretation of ^{143}Xe. Therefore, we reinvestigated this nucleus using data from a measurement of the γ rays following spontaneous fission of ^{248}Cm, performed with the EUROGAM 2 detector array [9]. Our measurement provided an order of magnitude more data than the run of Ref. [8]. More details about our experiment and data analysis can be found in our earlier paper [10].

We gated on γ lines of ^{143}Xe reported in Ref. [8] and found new lines, which enabled a rearrangement of the decay scheme proposed in Ref. [8]. In Fig. 1(a) we show a spectrum doubly gated on the 78.9-keV ground-state transition and the 244.0-keV line, which is a self-gating doublet [8]. In the spectrum, one observes other lines reported in Ref. [8], several lines from the complementary Mo isotopes [11,12], and a new line at 380.1 keV. Figure 1(b) shows a spectrum doubly gated on the 78.9- and 380.1-keV lines in which the known 244.0-keV line and new lines at 528.4 and 600.5 keV are seen. Lines from the complementary ^{102}Mo and ^{103}Mo isotopes are also presented, but no other known lines from ^{143}Xe are shown. This indicates that the 380.1-keV line belongs to a new cascade feeding the 323-keV level in ^{143}Xe reported in Ref. [8].

In Fig. 2(a) we show a spectrum doubly gated on the 78.9- and 193.8-keV lines. If the level scheme of ^{143}Xe proposed in Ref. [8] is correct, the γ intensity of the 224.4- and 244.2-keV lines should be similar. In Fig. 2(a), the γ intensity of the 244.2-keV line is 0.71 of the γ intensity of the 224.4-keV line. This difference cannot be accounted for by possible differences in conversion coefficients of the two transitions. (The total conversion coefficient for a 224.4-keV transition in Xe nuclei is smaller than 0.11.) Moreover, in Fig. 2(a) we observe a new line at 259.9 keV. In the spectrum doubly gated on the 193.8- and 259.9-keV lines, shown in Fig. 2(b), the 224.4-keV line dominates. The 78.9-keV line is also present, along with two new lines at 303.4 and 527.6 keV, but there is no line at 244 keV. The evidence in Fig. 2 indicates that a rearrangement of the level scheme proposed in Ref. [8] is in order to restore the intensity balance and to include the newly observed lines. Further gating provided an improved level scheme of ^{143}Xe, shown in Fig. 3, which satisfies these requirements.

We estimated the total conversion coefficient, $\alpha_{\rm tot}$, for the 78.9-keV transition by comparing the γ intensities of the 78.9- and 224.4-keV lines observed in the γ spectrum doubly gated on the 194- and 244-keV lines. (The theoretical

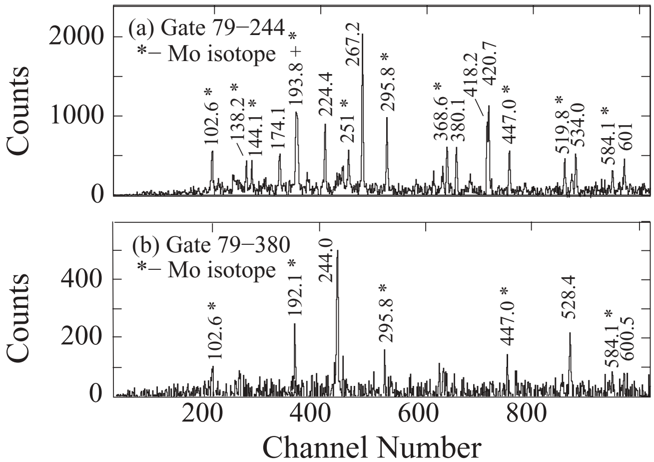

FIG. 1. The γ spectra doubly gated on lines in ^{143}Xe.

total conversion coefficient at 224.4 keV is less than 0.11.) The obtained experimental value, $\alpha_{\text{tot}} = 1.3(2)$, should be compared against theoretical values [13] of 0.41, 1.61, and 4.20 for the $E1$, $M1$, and $E2$ multipolarities, respectively. We also estimated the α_K conversion coefficient for the 78.9-keV transition, comparing the intensity of this line and the intensity of the X_K line of Xe, as seen in the spectrum measured by a low-energy photon spectrometer, which was doubly gated on the 418.2- and 244.2-keV lines. The experimental value of $\alpha_K = 2.4(6)$ should be compared against theoretical values of 0.35, 1.38, and 2.45 calculated [13] for $E1$, $M1$, and $E2$ multipolarities, respectively. Together, the α_{tot} and α_K values indicate an $M1 + E2$ multipolarity for the 78.9-keV transition. This differs from Ref. [8], which proposed an $E1$ multipolarity for the 78.8-keV transition, based on their $\alpha_{\text{tot}} = 0.4(34)$, which is less precise. We note that both works exclude a stretched $E2$ multipolarity for the 78.8-keV transition.

In Fig. 4 we show results for angular correlations obtained in this work. Experimental data points are compared to theoretical predictions [6,14] for various multipolarities of transitions in $\gamma\gamma$ cascades. (Here D denotes a stretched dipole and Q denotes a stretched quadrupole transition.) The angular correlation for the 267.2–420.7-keV cascade, shown in Fig. 4(a), indicates that both lines are stretched quadrupoles, while the correlation between the 267.2-keV line and the 244-keV doublet indicates that the 244.2-keV line, which dominates over the 244.0-keV line in the 267.2-keV gate, is not a stretched quadrupole transition. Correlations shown in Fig. 4(b) are consistent with a stretched quadrupole character for the 380.1- and 528.4-keV lines and a nonstretched ($\Delta I < 2$) character for the 244.0-keV line. Angular correlations in the 418.2-keV gate [Fig. 4(c)] are consistent with the 418.2- and 267.2-keV lines being stretched quadrupoles and the

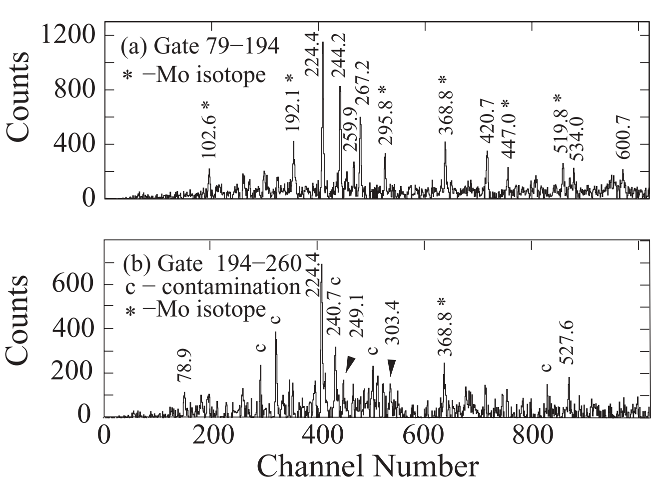

FIG. 2. The γ spectra doubly gated on lines in ^{143}Xe.

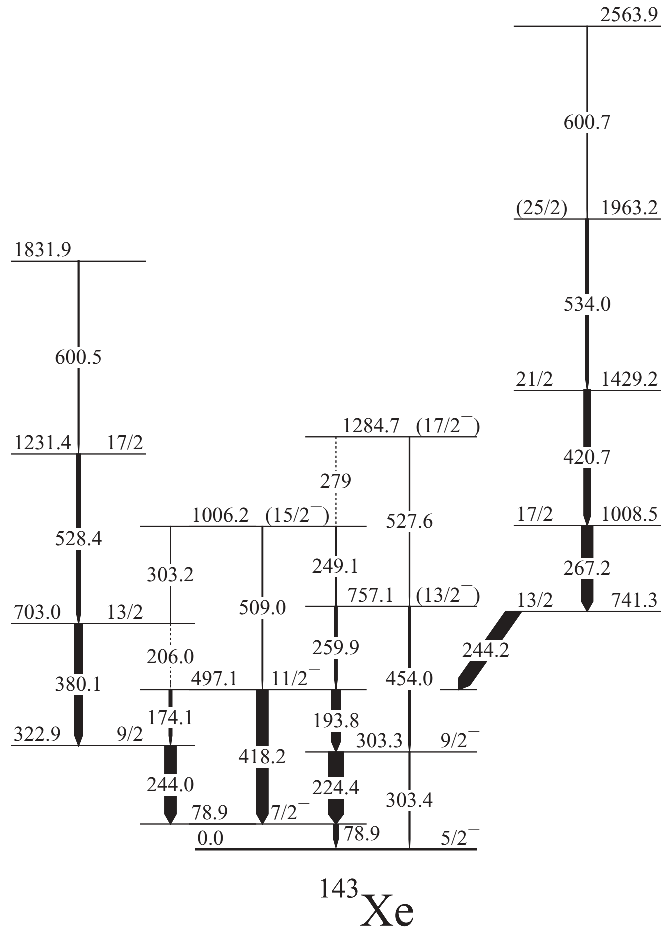

FIG. 3. Level scheme of ^{143}Xe obtained in the present work.

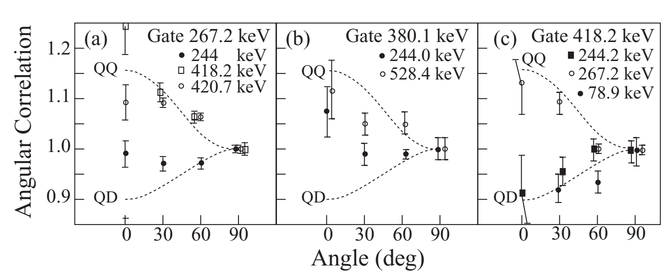

FIG. 4. Angular correlations for $\gamma\gamma$ cascades in ^{143}Xe, as measured in the present work.

TABLE I. Properties of γ transitions and excited levels in ^{143}Xe, as measured in this work.

E_γ (keV)	I_γ (rel.)	Multipolarity	E_{lev}^{ini} (keV)	I_{lev}^{ini}
78.9(1)	100 (15)	$M1+E2$, $\Delta I=1$	78.9	$7/2^-$
174.1(2)	14 (2)		497.1	$11/2^-$
193.8(1)	59 (5)		497.1	$11/2^-$
206.0(5)			703.0	13/2
224.4(1)	73 (5)		303.3	$9/2^-$
244.0(2)	57 (7)	$\Delta I=1$	322.9	9/2
244.2(2)	83 (6)	$\Delta I=1$	741.3	13/2
249.1(3)	12 (4)		1006.2	$(15/2^-)$
259.9(2)	25 (5)		757.1	$(13/2^-)$
267.2(1)	66 (5)	$E2$, $\Delta I=2$	1008.5	17/2
279.0(5)			1284.7	$(17/2^-)$
303.2(2)	8 (3)		303.3	$9/2^-$
303.4(3)	20 (5)		1006.2	$(15/2^-)$
380.1(1)	41 (6)	$E2$, $\Delta I=2$	703.0	13/2
418.2(1)	80 (5)	$E2$, $\Delta I=2$	497.1	$11/2^-$
420.7(1)	50 (4)	$E2$, $\Delta I=2$	1429.2	21/2
454.0(2)	15 (5)		757.1	$(13/2^-)$
509.0(3)	14 (4)		1006.2	$(15/2^-)$
527.6(3)	10 (5)		1284.6	$(17/2^-)$
528.4(1)	23 (4)	$E2$, $\Delta I=2$	1231.4	17/2
534.0(2)	33 (4)	$E2$, $\Delta I=2$	1963.2	(25/2)
600.5(3)	6 (2)		1831.9	
600.7(4)	17 (6)		2563.9	

244.2- and 78.8-keV lines corresponding to a $\Delta I = 1$ change in spin.

In Table I we show relative intensities of γ transitions in ^{143}Xe and the information on their multipolarites and initial levels. Multipolarities of transitions in ^{143}Xe were deduced, where possible, from the conversion coefficient estimates, from angular correlations, and from the observed intensity branching ratios. When assigning spins to excited levels, we assumed that spins are growing with excitation energy, which is commonly observed for excited states populated in spontaneous fission [15].

The new data indicate that the 741.3-keV level has spin 13/2. Its parity could not be deduced directly but the systematics of the $13/2^+$ relative to the $5/2^-$ excitation energy in the $N = 89$ isotones, shown in Fig. 5, strongly suggests that the parity of the 741.3-keV level is positive. At neutron number

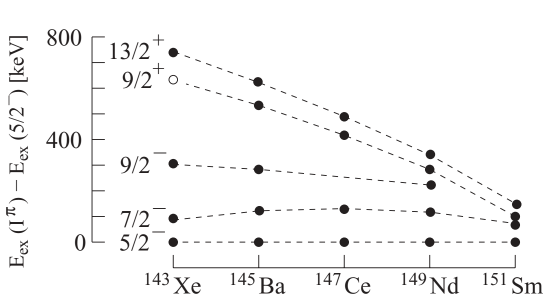

FIG. 5. Positions of bandheads in $N = 89$ isotones. The data are taken from Ref. [16].

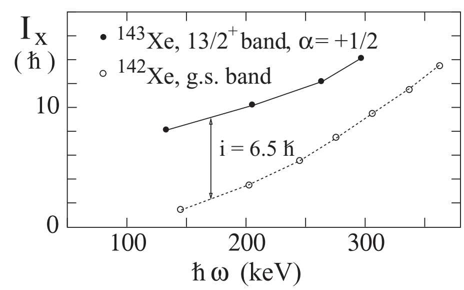

FIG. 6. Total aligned angular momentum in the band on top of the 741.3-keV level in ^{143}Xe, calculated assuming $K = 1/2$ for this band.

$N = 89$ the Fermi level approaches the $1/2^+[660]$ Nilsson orbital originating from the $i_{13/2}$ intruder shell. In Fig. 6 we show the total aligned angular momentum for the band on top of the 741.3-keV level in ^{143}Xe relative to the ground-state band in the ^{142}Xe core. The aligned momentum in this band of $i = 6.5\hbar$ indicates uniquely the $i_{13/2}$ origin of this band and is consistent with the population of the $1/2^+[660]$ orbital.

In Fig. 5 we also show positions of the $7/2_1^-$ and $9/2_1^-$ levels in the $N = 89$ isotones. The 78.8-keV level in ^{143}Xe fits well the trend for the $7/2_1^-$ levels, supporting its spin and parity assignment. In heavier $N = 89$ isotones this level is the first excited level in the band based on the $5/2^-[523]$ level and we propose the same interpretation for the 78.8 keV $7/2^-$ in ^{143}Xe. The $9/2^-$ level at 303.3 keV in ^{143}Xe follows the trend for the $9/2^-$ members of the ground-state configuration in $N = 89$ isotones and it is the second excited level in the $5/2^-[523]$ band.

The structure of the $N = 89$ isotones clearly differs from the structure of the $N = 85$ and $N = 87$ isotones. In $^{139}Xe_{85}$ [17] and $^{141}Xe_{87}$ [7], one observes decoupled bands originating from the $\nu f_{7/2}$ level and at $N = 87$ there are also decoupled bands originating from the $\nu h_{9/2}$ level. In contrast, at $N = 89$, strongly coupled bands are present. Their presence indicates an increase of nuclear deformation between $N = 87$ and $N = 89$.

The low position of the $5/2^-[523]$ configuration at $N = 89$ is unexpected, as mentioned before. This intriguing observation was also discussed in Ref. [18], where the authors concluded that octupole correlations are responsible for lowering the $5/2^-[523]$ configuration. Such an effect was predicted [3] and observed in ^{145}Ba [5], the $N = 89$ isotone of ^{143}Xe. Reference [18] suggested that the reflection-asymmetric orbitals persist at $N = 89$ down to the proton number $Z = 54$. Interestingly, we found [19] that $B(E1)/B(E2)$ branching ratios in ^{142}Xe increase by an order of magnitude, compared to lighter Xe isotopes. It is then likely that octupole correlations may play a role in ^{143}Xe.

To test the proposed configurations in ^{143}Xe we performed quasiparticle-rotor model (QPRM) calculations with a reflection-symmetric potential, using the codes GAMPN, ASYRMO, and PROBI [20]. We used a deformation of $\epsilon_2 = 0.15$ for both the positive-parity levels and the negative-parity levels, an inertia parameter $a = 23.3$ keV, and a Coriolis attenuation parameter $\xi = 0.70$. Standard values for the κ and μ parameters of the ls and l^2 terms were used [21]. To calculate

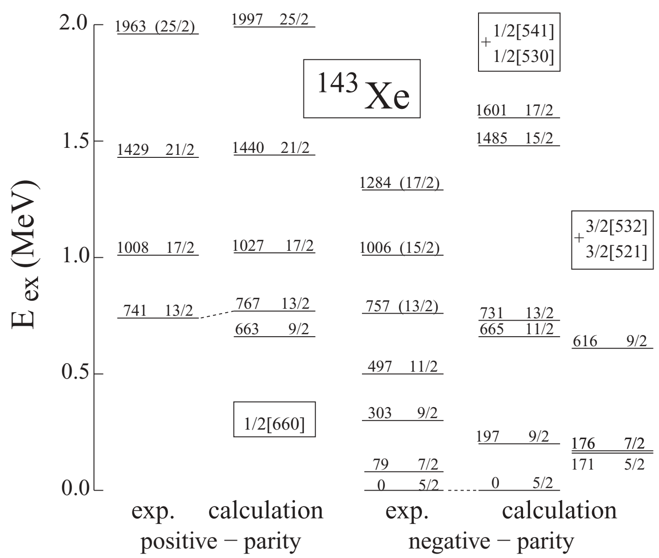

FIG. 7. Comparison of the experimental and calculated energies of excited states in ^{143}Xe, as obtained in the present work. Calculations are normalized to experiment at the $5/2^-$ level.

the γ-decay pattern we took a collective g factor for the core of $g_R = Z/A$ and an effective value of the free neutron g factor of $g_s^{\mathrm{eff}} = g_s^{\mathrm{free}}$.

The experimental and calculated excitation energies in ^{143}Xe are compared in Fig. 7. The energy of the $13/2^+$ level is reproduced well with the reflection-symmetric potential. Therefore, the mechanism proposed in Ref. [3] may not be needed to explain the relative positions of the $5/2^-$ and $13/2^+$ levels in ^{143}Xe. In our calculations a complex mixing of four orbitals, two with $K = 1/2$ (1/2[541] and 1/2[530]) and two with $K = 3/2$ (3/2[532] and 3/2[521]), produces the $5/2^-$ low-energy solution.

Finally, we comment on the 322.9-keV level in ^{143}Xe, with spin 9/2 and unknown parity. Two low-lying $9/2^-$ levels, originating from the $\nu f_{7/2}$ and $\nu h_{9/2}$ orbitals, are expected in $N = 89$ isotones. Strong mixing between these orbitals repels solutions with the same spin. In Fig. 7 the $9/2_1^-$ and $9/2_2^-$ levels are calculated more than 400 keV apart. This suggests that the 322.9-keV level in ^{143}Xe should not have negative parity. Positive parity for the 322.9-keV level would indicate the presence of octupole correlations in ^{143}Xe, because it is not likely that a $9/2^+$ at 322.9 keV would correspond to the $9/2^+$ member of the $i_{13/2}$ decoupled band, expected about 100 keV below the $13/2^+$, as observed in heavier $N = 89$ isotones (see Fig. 5). The $9/2^+$ member of the $i_{13/2}$ band in ^{143}Xe is calculated at 662 keV, fitting well the trend (open circle in Fig. 5).

The present data do not provide a clear answer about the role of octupole correlations in ^{143}Xe. On one hand, QPRM calculations with a reflection-symmetric potential can reproduce the $5/2^-$ spin and parity for the ground state. However, a rather poor reproduction of other negative-parity levels suggests that this may be an accidental result and that the mechanism proposed in Ref. [3] is valid. Finding of the parity of the $9/2_2$ level might resolve this problem. A systematic study of the properties of analogous $9/2_2$ levels in the $N = 89$ isotones should help in achieving this goal.

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