Observation of the lowest energy γ-ray in any superdeformed nucleus : ^{196}Bi

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New results on the superdeformed ^{196}Bi nucleus are reported. We have observed with the EUROBALL IV γ-ray spectrometer array a superdeformed transition of 124 keV which is the lowest observed energy γ-ray in any superdeformed nucleus. We have developped microscopic cranked Hartree-Fock-Bogoliubov calculations using the SLy4 effective force and a realistic surface pairing which strongly support the $K^\pi = 2^-(\pi[651]1/2\otimes\nu[752]5/2)$ assignment of this superdeformed band.

PACS numbers: 21.60.-n 23.20.Lv 27.80.+w

ccsd-00003090, version 1 - 18 Oct 2004

While impressive results exist on the superdeformation phenomenon on Au, Hg, Tl and Pb isotopes, very scarce data are available beyond Z=82 in the A$\sim$190 mass region. Only four yrast superdeformed (SD) bands are known in the ^{195,196,197}Bi [1, 2] and ^{198}Po[3] isotopes.

In order to deepen our knowledge of the valence SD orbitals in Z=83, high spin states of the ^{196}Bi nucleus have been reinvestigated with the EUROBALL IV γ-ray spectrometer [4]. In this brief report, we present the first result obtained in ^{196}Bi, a 124 keV γ-ray transition which is the lowest γ-ray ever observed in any SD nuclei with the exception of the fission isomers. This line is interpreted as the $9^- \rightarrow 7^-$ transition of the $K^\pi = 2^-$ yrast SD band in the framework of self-consistent lattice microscopic calculations.

The SD states of ^{196}Bi were populated in the ^{19}F(^{184}W,7n) reaction at a beam energy of 114 MeV. The beam was delivered by the VIVITRON accelerator at the IReS laboratory in Strasbourg. The target consisted of three ^{184}W foils of thickness 200, 125 and 125 μg/cm^2 mounted on thin carbon supports. The γ-rays were detected with the EUROBALL IV spectrometer [4] which comprised an inner-ball of 210 BGO crystals and 71 Compton-suppressed Ge detectors. Our automatic procedure based on the fuzzy set theory [5] has been applied for the energy calibration of the corresponding 239 Ge crystals. A condition of four unsuppressed Ge detectors firing in coincidence combined with an inner-ball multiplicity more than 7 was required to record events on DLT tapes. After presorting (prompt-time window, add-back of the Clover and Cluster composite detectors, Compton rejection), the data set finally consists of 2×10^9 three- and higher-fold events.

In fig. 1, we present a four-gated spectrum obtained in this experiment. The energies of the SD transitions obtained are presented in table 1. We confirm the 13 transitions observed by Clark et al. [1, 2] with GAMMASPHERE in double-gated spectra. The most striking

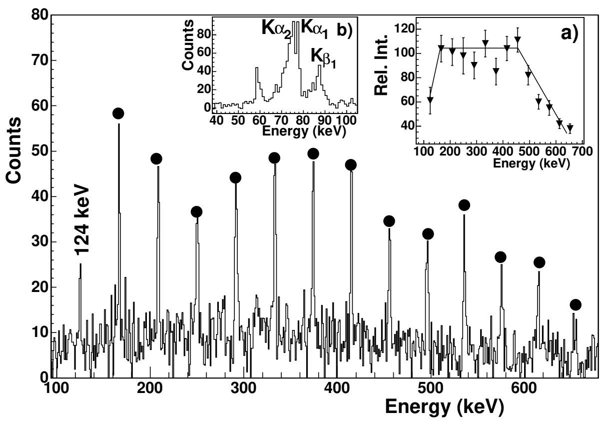

FIG. 1: Four-gated spectrum obtained with our EUROBALL IV experiment showing the new 124 keV transition. The dots indicate the positions of the other SD transitions. The relative intensity pattern of the yrast SD band in ^{196}Bi and the region of the spectrum around the X-rays are plotted in the inserts a) and b).

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TABLE I: Energies, relative intensities and spins proposed for the ^{196}Bi yrast SD band transitions. A 100 % intensity is obtained for the plateau.

E_γ (keV)	I_{tot}(%)	Spin ($\hbar$)
124.0(3)	**62(11)**	$(9) \rightarrow (7)$
165.7(4)	104(10)	$(11) \rightarrow (9)$
207.6(4)	100(10)	$(13) \rightarrow (11)$
249.5(4)	98(15)	$(15) \rightarrow (13)$
290.9(4)	90(10)	$(17) \rightarrow (15)$
332.6(4)	108(11)	$(19) \rightarrow (17)$
373.5(4)	85(11)	$(21) \rightarrow (19)$
413.3(4)	104(10)	$(23) \rightarrow (21)$
454.6(5)	111(10)	$(25) \rightarrow (23)$
494.8(5)	82(8)	$(27) \rightarrow (25)$
535.1(5)	60(6)	$(29) \rightarrow (27)$
574.9(5)	55(6)	$(31) \rightarrow (29)$
614.0(6)	42(4)	$(33) \rightarrow (31)$
654.2(8)	38(4)	$(35) \rightarrow (33)$

new result is the presence of a new SD transition at the bottom of the band with energy of 124.0 keV. The intensity pattern for this band, corrected for internal conversion assuming E2 character for all the transitions, is presented in the insert a) of fig. 1. It is worth noting that the measurement of the 124 keV intensity allows us to exhibit an extremely rapid de-excitation in only one transition after the plateau (with an intensity decrease of roughly 40 %).

Despite a large statistic, no normally deformed (ND) transition is observed in coincidence with the SD band. However the insert b) of fig. 1 presents the low energy part of the spectrum showing that the SD transitions are in coincidence with the X-rays of bismuth (K_{α_1}=77.107 keV,K_{α_2}=74.815 keV, K_{β_1}=87.349 keV). We finally adopt the assignment to the ^{196}Bi given by Clark et al. [1, 2].

The new 124 keV transition extends the flat behaviour of the dynamical moment of inertia $\Im^{(2)}$ of the yrast SD band in ^{196}Bi down to very low frequencies as illustrated in fig. 2.

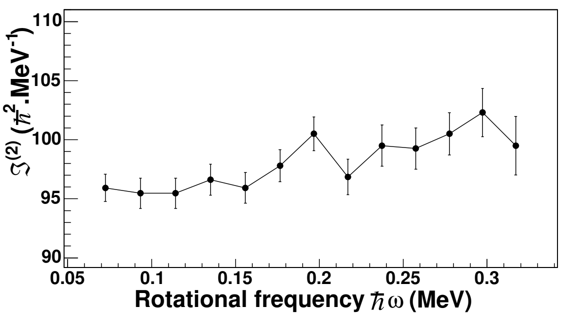

FIG. 2: Dynamical moment of inertia $\Im^{(2)}$ of the yrast SD band in ^{196}Bi.

We have applied the approach of Deloncle et al. [6] to estimate the maximum spin transferred in the recoiling nucleus. In A$\sim$190 mass region, the variation of the maximum spin observed in a SD band versus the Z^2/A fissility parameter is roughly linear with a change of around 9 per unit of Z^2/A. By an extrapolation to ^{196}Bi we obtain a maximum spin reached of 35$\pm$2$\hbar$. Considering the high sensitivity of our measurements the 654 keV transition is certainly the uppest transition (no higher-energy transition does exist) and corresponds to a $35\hbar \rightarrow 33\hbar$ transition. The lowest spin is then expected to be 7$\pm$2$\hbar$. The resulting spin values included in table 1 are in agreement with the spin assignment obtained by the Harris [7] and Wu [8] approaches. A carefull search of other SD bands in our data has succeeded in retrieving several SD bands in Tl, Pb isotopes and one in ^{197}Bi populated according to the PACE predictions [9]. However no excited SD band in ^{196,197}Bi has been observed.

In addition, we have performed to interpret the data static and cranked Hartree-Fock-Bogoliubov (HFB) calculations applied to the adjacent even-even ^{198}Po (Z=84 and N=114) nucleus. These lattice calculations have been performed using the SLy4 parametrization of the Skyrme nucleon-nucleon effective interaction for the particle-hole channel [10]. The pairing correlations (the particle-particle channel) have been taken into account via a zero range density-dependent interaction localized at the surface of the nucleus with the same parameters used for heavy nuclei of A$\sim$150 and A$\sim$250 mass regions [11–14]. To restore partially the particle number symmetry the Lipkin-Nogami prescription has been used. Our calculations have been performed in a tridimensional lattice and the size of the box was 40×40×40 fm^3 with a mesh of 0.8 fm.

Our static calculations localize the SD minimum at a mass quadrupole moment Q_{20} of around 5200 fm^2 (charge quadrupole moment Q_{2c} of 2270 e.fm^2, deformation parameter $\beta \sim$0.6) similar to the result obtained using the D1S Gogny Force [15]. The quasi-particle routhians shown in fig. 3 have then been calculated for this minimum. It appears that, at low frequency, the lowest available configuration is one quasi-particle (qp) proton in the π[651]1/2 orbital coupled to one qp neutron in the ν[752]5/2 orbital.

At low frequencies, in the framework of the strong coupling scheme, the configuration π[651]1/2$\otimes\nu$[752]5/2 gives rise to two doublets of bands with K$^\pi$ = 2$^-$ and 3$^-$, the first one being favoured by the Gallagher-Moskowski rule [16]. However, in our experiment we have observed no excited band which would correspond to the signature partner. The Coriolis coupling between the K$^\pi$ = 2$^-$ and K$^\pi$ = 3$^-$ bands, the mixing of other configurations, and also the residual proton-neutron interaction could be responsible of the lowering of the favoured signature partner of the K$^\pi$ = 2$^-$ band. This band coming from $\pi[651]1/2(\alpha = -1/2) \otimes \nu[752]5/2(\alpha = -1/2)$ has a total signature $\alpha_{tot} = -1$ and an odd spin sequence

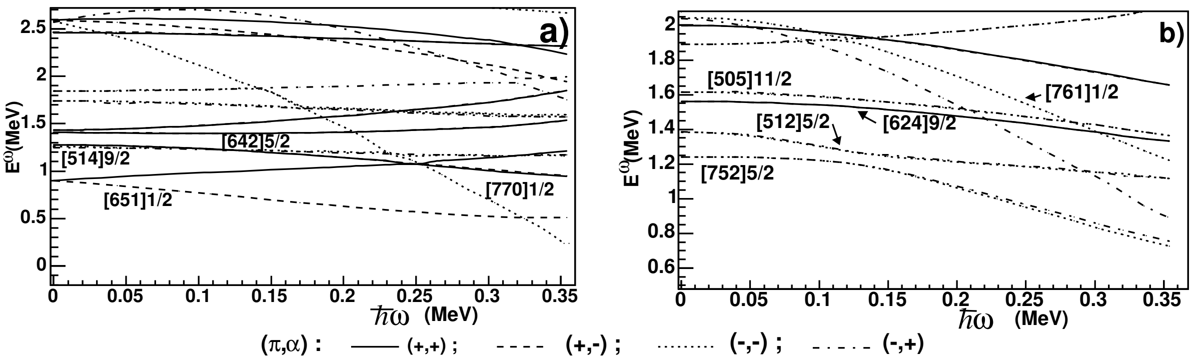

FIG. 3: Quasi-particle routhians E^{ω} of ^{198}Po as function of the rotational frequency for protons (a) and neutrons (b) obtained with cranked Hartree-Fock-Bogoliubov calculations.

(3^-,5^-,7^-,...).
This interpretation based on our self-consistent mean-field calculations is in accordance with the results obtained with phenomenologic cranked Wood-Saxon calculations [1, 2] in which the [752]5/2 orbital exhibits an immediate splitting of the two signature partners, the $\alpha = -1/2$ partner being favoured as the rotational frequency increases. In our calculations the splitting of the [752]5/2 orbital is less pronounced (the two signature partners are nearly degenerate up to high frequencies) and we cannot totally reject an interpretation based on the $\pi[651]1/2(\alpha = -1/2) \otimes \nu[752]5/2(\alpha = 1/2)$ configuration for the yrast SD band leading to the even spin sequence I=(2^-,4^-,6^-,...). However we have finally adopted that the favoured configuration remains the $\pi[651]1/2(\alpha = -1/2) \otimes \nu[752]5/2(\alpha = -1/2)$ with an odd spin sequence for the SD band.

This imposes the last SD transition we have observed in ^{196}Bi, namely the 124 keV line, to be the $9^- \rightarrow 7^-$. Two supplementary transitions (highly converted) should exist to reach the 3^- SD state of the favoured signature of the K^{π}=2^- band. A similar situation occurs in ^{194}Pb [17] where the lowest proposed SD transition was $6^+ \rightarrow 4^+$ compared to the SD band head of 0^+.

In conclusion, in order to study the superdeformation phenomenon above $Z = 82$, we have populated the ^{196}Bi nucleus in an experiment with the EUROBALL IV array. In the yrast SD band of this isotope we have identified a transition of 124 keV energy which is the lowest γ-ray energy observed in any SD nucleus with the exception of the fission isomers. This SD band of ^{196}Bi has been interpreted as built on the configuration $(\pi[651]1/2 \otimes \nu[752]5/2) K^{\pi} = 2^-$, and the 124 keV γ-ray is proposed to be the $9^- \rightarrow 7^-$ transition.

Acknowledgments

We would like to thank all those involved in the setting up and commissioning of EUROBALL IV. We are also very indebted to the operators of the VIVITRON tandem who have provided us a very stable ^{19}F beam during the six days of the experiment. We would like to thank J. Meyer for enlightening and helpful discussions. The work of the Bonn Group was supported by BMBF contract no 06 BN 907.

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