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

Observation de la transition $\gamma$ d'énergie la plus basse pour un noyau superdéformé : $^{196}$Bi

Prévos A, Astier A, Deloncle I, Porquet M-G.

Collaboration: Institut de Physique Nucléaire de Lyon, Argonne National Laboratory, Université de Bonn, Institut de Recherches Subatomiques de Strasbourg

Résumé: De nouveaux résultats concernant l'isotope superdéformé $^{196}$Bi sont présentés. Nous avons observé avec le spectromètre gamma EUROBALL 4 une transition de 124 keV, qui est la plus basse énergie observée à ce jour dans un noyau superdéformé.

Nous avons effectué des calculs microscopiques Hartree-Fock-Bogoliubov tournants utilisant la force effective Sly4 et un appariement de surface réaliste qui nous ont permis d'attribuer la configuration $K^\pi=2^-$ ($\pi[651]1/2 \otimes \nu[752]5/2$) à cette bande superdéformée.

Introduction

While impressive results exist on the superdeformation phenomenon in the A~190 mass region, namely on Au, Hg, Tl and Pb isotopes, very scarce data are available beyond Z=82. Only four yrast superdeformed (SD) bands are known in the $^{195,196,197}$Bi [1, 2] and $^{198}$Po isotopes [3]. 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 4 $\gamma$-ray spectrometer [4]. Here we present the first result obtained in $^{196}$Bi, a 124 keV $\gamma$-ray transition which is the lowest $\gamma$-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 lattice self-consistent microscopic calculations.

I – Experimental conditions

The SD states of $^{196}$Bi were populated by 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 $\gamma$-rays were detected with the EUROBALL 4 spectrometer [4] which comprised 71 Compton-suppressed Ge detectors and an inner-ball of 210 BGO crystals. Our automatic procedure based on the fuzzy set theory [5] has been applied in this experiment for the energy calibration of the 239 Ge crystals of EUROBALL 4. A condition of 4 unsuppressed detectors firing in coincidence combined with an inner-ball multiplicity of more than 7 was required to record events on DLT tapes. After pre-sorting (prompt time-window, add-back of the Clover and Cluster composite detectors, Compton rejection), the data set finally consists of $2x10^9$ three- and higher-fold events.

II - Results

In figure 1 is presented a four-gated spectrum obtained in our experiment with EUROBALL 4. We confirm the 13 transitions observed by Clark et al. [1,2] with GAMMASPHERE in double-gated spectra. The most striking new result is the presence of a new SD transition at the bottom of the band with energy of 124.0(3) keV. The intensity pattern for this band corrected for internal conversion assuming E2 character for all the transitions is presented in the insert of figure 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%). In addition, one may note that the new 124 keV transition extends the flat behaviour of the dynamical moment of inertia of the yrast SD band in $^{196}$Bi down to very low frequencies.

Figure 1: Four-gated spectrum obtained with our EUROBALL 4 experiment showing the new 124 keV transition of the yrast SD band in $^{196}$Bi. The squares indicate the position of the other SD transitions. The relative intensity pattern of the band is plotted in the insert.

The approach of Deloncle et al. [6] has been applied to estimate the maximum spin transferred in the recoiling nucleus. In the A~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 extrapolation to $^{196}$Bi we obtain a maximum spin reached of 35±2ħ. Considering the sensitivity of our measurements we are confident in the fact that the 654 keV transition is really the last transition (i.e. no higher-energy transition does exist) and corresponds to a 35ħ→33ħ transition. The lowest spin is then expected to be a 7±2ħ. It agrees with the spin assignment obtained by the Harris [7] and Wu [8] approaches. A careful search of other SD bands in our data has successfully retrieved several SD bands in TI, 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.

III - Discussion

In order to interpret our results, we have performed static and microscopic Hartree-Fock-Bogoliubov (HFB) calculations for the adjacent even-even $^{196}$Po ($Z=84$, $N=114$) nucleus. These lattice calculations have been performed using the SLy4 parameterisation of the Skyrme nucleon-nucleon interaction for the particle-hole channel [10]. The pairing correlations 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~150 and A~250 mass regions [11-14]. To restore approximately the particle number symmetry the Lipkin-Nogami prescription has been used.

From the static calculations the SD minimum is located at a mass quadrupole moment $Q_{20}$ of around 5200 fm$^2$ (corresponding to a charge quadrupole moment $Q_{2c}$ of 2270 e.fm$^2$ and to a deformation parameter $\beta\sim0.6$), similar to the result obtained using the D1S Gogny force [15]. The quasi-particle (qp) routhians shown in figure 2 have then been calculated for this minimum. It clearly appears that, at low frequency, the lowest available configuration is one qp proton in the $\pi[651]1/2$ orbital coupled to one qp neutron in the $\nu[752]5/2$ orbital.

At low frequencies, in the framework of the strong coupling scheme, the configuration $\pi[651]1/2\otimes\nu[752]5/2$ should give rise to two doublets of bands with $K^\pi=2^-$ and $3^-$, the first one being favoured by the Gallagher-Moszkowski 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 $\alpha=-1$ and an odd spin sequence $I=3,5,7...$
Figure 2: Quasi-particle routians E° of 199Po as function of the rotational frequency for protons (a) and neutrons (b) obtained with cranked Hartree-Fock-Bogoliubov calculations.

\[ (\pi,\alpha): \rightarrow (+,+); \cdots (+,-); \cdots (-,+); \cdots (-,-) \]

This interpretation based on our self-consistent mean-field calculations is in accordance with the results obtained with phenomenological cranked Wood-Saxon calculations [1, 2] in which the \( v[752]5/2 \) 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 this splitting is less pronounced (the two partners are nearly degenerate up to high frequencies) and we cannot totally reject an interpretation based on the \( \pi[651]1/2(\alpha=-1/2) \otimes v[752]5/2(\alpha=1/2) \) configuration for the yrast SD band leading to the even spin sequence \( I=2,4,6 \ldots \). However we have finally adopted that the favoured configuration remains \( \pi[651]1/2(\alpha=-1/2) \otimes v[752]5/2(\alpha=1/2) \) with an odd spin sequence for the SD band.

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

**Conclusion**

In order to study the superdeformation phenomenon above \( Z=82 \), we have populated the \(^{196}\)Bi nucleus in an experiment with the EUROBALL 4 array. In the yrast SD band of this isotope we have identified a transition of 124 keV energy which is the lowest \( \gamma \)-ray energy observed in any SD nuclei with the exception of the fission isomers. This SD band of \(^{196}\)Bi has been interpreted as built on the configuration \( \pi[651]1/2 \otimes v[752]5/2 K^{\pi}=2^{+} \), in which the 124 keV \( \gamma \)-ray is proposed to be the \( 9 \rightarrow 7 \) transition.

The results of this work are included in a paper submitted to Phys. Rev. C [18].