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Spectroscopy of $^{193}\text{Bi}$

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Abstract. An experiment aiming to study the shape coexistence in $^{193}\text{Bi}$ has been performed at the Accelerator laboratory of the University of Jyväskylä, Finland (JYFL). Many new states have been found, hugely extending the previously known level scheme of $^{193}\text{Bi}$. The \( I^+ = \frac{29}{2}^+ \) member of the \( \pi_{13/2} \) band de-excites also to the previously, only tentatively placed long-lived isomeric state. This link determines the energy of the isomeric state to be 2260(1) keV and suggests a spin and parity of \( (\frac{27}{2}^+ \) ). The half-life of the isomeric state was measured to be 84.4(6) \( \mu \)s. A level structure on top of this isomeric state was constructed. However, transition directly depopulating this state could not be identified. A superdeformed band almost identical to that present in the neighboring isotope $^{191}\text{Bi}$ has been identified.

1 Introduction

In certain nuclear mass regions, low-lying excited states can be associated with a variety of nuclear shapes. One such region with the large selection of nuclei in which coexistent deformed configurations at relatively low excitation energies have so far been observed, has a proton number close to the magic \( Z = 82 \) and lie in the neutron mid-shell region. There have been two main approaches on how to explain these structures, namely either the intruder picture, associated with shell-model intruder states formed by exciting protons across the magic shell gap [1] or an alternative approach provided by the Nilsson model [2]. As the bismuth nuclei have only one extra proton coupled to \( Z = 82 \) proton magic lead core, $^{193}\text{Bi}$ is a unique nucleus for the investigation of the shape coexistence and studies of the isomeric states built on the multiquasiparticle configurations. $^{193}\text{Bi}$ has shown itself to be just on the edge between very neutron deficient odd-A prolate bismuth nuclei on the left [3] and heavier odd-A bismuth isotopes with the absence of any regular bandlike structures for the low-lying states on the right in the chart of nuclei [4]. Moreover, searching for highly excited superdeformed bands for better understanding of nuclear properties under extreme deformation has proven itself to be very efficient in this region of the nuclear chart [5].

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2 Experimental setup

The $^{193}$Bi nuclei were produced in the total fusion-evaporation reaction $^{165}$Ho($^{32}$S,4n)$^{193}$Bi at the bombarding energy of 152 MeV. The reaction products were studied using in-beam $\gamma$-ray spectroscopy combined with decay spectroscopy. The fully digitized JUROGAM2 array was used to detect prompt $\gamma$ rays at the target position. The array consisted of 24 Clover and 10 Phase1 or GASP Compton-suppressed HPGe-detectors. The JUROGAM2 array was coupled to the gas-filled high-transmission recoil separator RITU [6] to separate the nuclei of interest from the unwanted beam and beam-like components. The ions transported through the separator were subsequently implanted in the GREAT focal plane spectrometer system [7] for the identification of fusion products of interest. The main instrument of the GREAT spectrometer - the double-sided silicon strip detector (DSSD) was used for the implantation of the fusion evaporation recoils and for the detection of their subsequent decays such as $\alpha$ decay (DSSD-Y side) or internal conversion (DSSD-X side). To collect the $\alpha$ particles and conversion electrons that have escaped from the DSSD, the PIN silicon detectors were mounted in a box arrangement upstream from the DSSD. A planar Ge-detector was mounted directly behind the DSSD to detect low energy $\gamma$ rays and X-rays. A set of three clover Ge-detectors was added to face the GREAT chamber from the sides and from above to detect higher energy $\gamma$ rays. All data channels were recorded synchronously using the triggerless total data readout (TDR) [8] data acquisition system. This allowed for using the very selective recoil-decay tagging, isomer-tagging and recoil gating techniques [9].

3 Results

3.1 Long-lived isomer

In the present work, the half-life and excitation energy of the long-lived isomer, only tentatively placed in the previous work [10], together with the transitions (see Fig. 1) feeding the isomeric state, have been unambiguously determined: $T_{1/2} = 84.4(6)$ $\mu$s (see Fig. 2), $E_{ex} = 2260(1)$ keV. This isomeric state is partially populated by the decay of the recently found higher lying states of the $\pi i_{13/2}$ band, indicating the spin and parity of this state to be $\left(\frac{27}{2}^+\right)$. The spin and parity of the states shown in Fig. 1 have been determined and confirmed, respectively, by the angular distribution (DCO) and $\gamma$-ray linear polarization measurements. We suggest the configuration of this isomer to be $\pi h_{9/2}$ coupled to the isomeric $9^-$ state of the $^{192}$Pb core, which would be the maximum allowed spin for such configuration. Since no transition corresponding to the energy difference of $\sim 131$ keV is seen in the focal plane $\gamma$-ray spectra or in the PIN diodes spectra, this isomeric state most likely decays via cascade of the low energy, highly converted transitions, overcoming the spin difference of $\Delta j = 4\hbar$ ($\frac{27}{2}^+ \rightarrow \frac{19}{2}^+\), see Fig. 1). None of these transitions could be firmly identified in the planar Ge-detector intended for detecting low energy $\gamma$ rays or in the PIN diodes meant for detecting conversion electrons.
Figure 1. (Color online) Partial level scheme of $^{193}\text{Bi}$, showing the structure built on top of the long-lived isomer with only tentative spin assignment of the states, together with the feeding of the long-lived isomer from the upper part of the $\pi_{13/2}$ band. Red-border arrow indicates a cascade of the low-energy transitions discussed above.

Figure 2. Time difference spectrum of the recoil formation and observation of the 455 keV transition (as one of the many transitions below the long-lived isomer) in the focal plane clover detector. The exponential decay law was fitted to the data and is shown as the solid line through data points.
3.2 Superdeformed band

A superdeformed band has been identified in $^{193}$Bi. The spectrum gated on the transitions in band is shown in Fig. 3. In contrast with $^{193}$Bi, two superdeformed bands have been found in $^{191}$Bi [11]. They are interpreted as signature partner bands built on the proton $i_{11/2}^{1+}$ [$651$] configuration. The newly found band in $^{193}$Bi is identical to the other of the bands in $^{191}$Bi. In both nuclei, superdeformed bands were found in the data obtained by tagging on alpha decays of the $\frac{1}{2}^+$ intruder states. However, no connecting links have been found yet.

![Figure 3. The γ-ray spectrum of the superdeformed band assigned to $^{193}$Bi as found in the $\frac{1}{2}^+$ proton intruder α-decay tagged spectrum.](image)

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