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GAMMA-RAY SPECTROSCOPY OF $^{191,193}$Bi*

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Very neutron-deficient $^{191,193}$Bi nuclei have been studied at the Department of Physics, University of Jyväskylä, Finland (JYFL) employing the Jurosphere II Ge-detector array coupled to the gas-filled recoil separator RITU and different tagging techniques. For the first time in heavy odd-mass nuclei, a collective band (oblate) is identified above the $2\text{p}$-$1\text{h}$ $(1/2^+)$ proton intruder state in $^{191}$Bi. In both $^{191,193}$Bi, a band based on isomeric $13/2^+$ state has been observed and oblate deformation for this state has been deduced.

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1. Introduction

Low lying proton intruder states are known in many odd-Z nuclei near the $Z = 82$ shell closure and associated with oblate-deformed shapes. Intruder $2p-1h$ ($1/2^+$) states in odd-mass Bi isotopes are observed between the closed neutron shell nucleus $^{209}$Bi and the mid-shell nucleus $^{187}$Bi [1, 2] (Fig. 1). The excitation energy of these states decreases with decreasing neutron number and the reduction continues even at the mid-shell. This is unique compared to other odd-mass nuclei (see, for example, Tl in Fig. 1), where the excitation energies of intruder states have a parabolic behaviour as a function of neutron number with a minimum close to the mid-shell. One possible explanation for this behaviour in Bi isotopes is that near the mid-shell, instead, a prolate $1/2^+$ state is observed [3].

![Graph showing the excitation energy of Bi isotopes as a function of neutron number.](image)

Fig. 1. Behaviour of the $13/2^+$ isomeric and the $1/2^+$ intruder state in Bi and the $9/2^-$ intruder state in Tl as a function of neutron number with respect to the ground state.

In Bi isotopes, an isomeric $13/2^+$ state feeding the $9/2^-$ ground state is seen and interpreted as a $\pi i_{13/2}$ state coupled to the even-even Pb core. The reason for the sudden reduction of excitation energy of this state with decreasing neutron number (see Fig. 1) could be either the increasing interaction of the $\pi i_{13/2}$ state with the $\nu i_{13/2}$ hole states which open up below $A = 197$, or a change in the underlying Pb core.

In this contribution, observation of states built on the $1/2^+$ state in $^{191}$Bi, isomeric transitions de-exciting the $13/2^+$ states and band structures built on these states in $^{191,193}$Bi, are reported.
2. Experimental methods

The heavy ion beams used in the present work were delivered by the K130 cyclotron and fusion evaporation residues were separated using the gas-filled separator RITU [4]. Prompt $\gamma$-rays were observed with 27 Compton suppressed HPGe detectors in the Jurosphere II array with absolute photopeak efficiency of $\sim$1.7\% at 1.3 MeV. At the focal plane, recoils were implanted into a position sensitive silicon detector and $\gamma$-rays were detected with five Compton suppressed HPGe detectors close to the silicon detector. A Multiwire Proportional Avalanche Counter (MWPAC) was installed upstream from the silicon detector to separate recoil- and $\alpha$-particle-like events with overlapping energies.

In the Recoil-Decay Tagging (RDT) method, recoils of interest are identified by observing their characteristic $\alpha$-decay in the same silicon detector pixel within a time window depending on the $\alpha$-decay half-life and implant rate. Prompt $\gamma$-rays observed in coincidence with the recoil and delayed $\gamma$-rays in coincidence with the $\alpha$-decay are associated with the nucleus of interest. If a prompt or a delayed $\gamma$-ray is known, method of recoil gating or isomer tagging can be used.

3. Results

The nucleus $^{191}$Bi was produced in the $^{142}$Nd($^{52}$Cr,p2$n$) reaction and $\sim$340000 $\alpha$-decays of the 9/2$^-$ ground state and $\sim$60000 $\alpha$-decays of the 1/2$^+$ intruder state were observed. An RDT analysis was performed to find states built on the 1/2$^+$ state. A collective band was observed (Fig. 2(a)). A 429 keV $\gamma$-ray line in the focal plane spectrum was assigned to the isomeric 13/2$^+$ to 9/2$^-$ transition, for which a half-life of 533(7) ns was deduced. Recoil gating was used to build the tentative level scheme feeding the isomer (Fig. 2(b)).

The nucleus $^{193}$Bi was produced by bombarding a $^{165}$Ho target with a $^{32}$S beam at energies from 144 to 159 MeV in 5 MeV steps. About 230000 $\alpha$-decays of the 9/2$^-$ state and $\sim$170000 $\alpha$-decays of the 1/2$^+$ state were observed. Due to the long $\alpha$-decay half-life of the 9/2$^-$ state (67 s), no correlation methods for this decay could be used. Knowing the energies of the 13/2$^+$ to 9/2$^-$ transitions in $^{195}$Bi [5] and in $^{191}$Bi and by comparing the excitation functions of candidate $\gamma$-ray lines in the expected energy range to that of the $\alpha$-decay of the 9/2$^-$ state, a 605 keV $\gamma$-ray line was assigned to this transition in $^{193}$Bi. The tentative level scheme feeding the isomer is shown in Fig. 2(c).
Fig. 2. (a) Prompt $\gamma$-rays tagged with the $^{191}$Bi $1/2^+$ intruder state $\alpha$-decay, the level scheme as an inset. (b) Band built on the $13/2^+$ state in $^{191}$Bi and (c) in $^{193}$Bi.

4. Discussion

The sequence of levels in the band based on the $1/2^+$ state in $^{191}$Bi is quite similar to the extrapolated oblate band based on the $0^+$ intruder state in $^{192}$Po [6]. This implies that indeed, also the $1/2^+$ intruder state in $^{191}$Bi is oblate deformed and that the predicted crossing of two different $1/2^+$ states [3] has not yet taken place in $^{191}$Bi.

The energies of the observed $13/2^+$ isomeric states in $^{191,193}$Bi continue the decreasing trend (Fig. 1). Strongly coupled bands identified above these $\pi_{13/2}^+$ states indicate oblate deformation. The reason for the reduction of excitation energy could be better understood if information concerning this state in still more neutron-deficient Bi isotopes could be obtained.
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