IMPROVED HALF-LIVES OF 8^+ AND 11^- ISOMERIC STATES IN ^{202}Po*

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The level structure of ^{202}Po was studied using the ^{195}Pt(^{12}C, $5n$) reaction at a beam energy of 83 MeV. Improved lifetime measurements have been performed for the 8^+ and 11^- isomeric states by the decay slope method using high-purity germanium clover detectors. The half-lives of these isomeric states were found to be $T_{1/2}(8^+) = 114 \pm 5$ ns and $T_{1/2}(11^-) = 83 \pm 6$ ns. The variation of the reduced transition probabilities with neutron and proton number in the decay of these proton-dominated isomeric states is discussed.

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1. Introduction

Nuclei close to the doubly-magic spherical shell closure at $Z = 82$ exhibit both single-particle excitations at low spins and a variety of collective

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rotational behavior [1] at high spins. In even–even $^{200-208}$Po isotopes with two protons above the $Z = 82$ shell closure, excited states are generated mainly by two quasi-protons and two quasi-neutrons [2, 3]. Many efforts have been made to understand the low-lying states in these isotopes [4, 5]. New measurements have also been performed at the CERN-ISOLDE facility using the in-source laser spectroscopy and multi-step Coulomb excitation. Their results served as a test for recent nuclear-structure calculations and hint towards an early departure of Po isotopes from sphericity when moving away from the $N = 126$ shell closure, as compared to the neighboring $Z \leq 82$ isotones (Refs. [6, 7] and references therein). An interesting feature is the existence of several isomeric states due to different neutron–proton configurations, well known among these being the 8^+ isomers classified as fairly pure $\pi(h_{9/2})^2$ states [8, 9]. The yrast 11^- isomeric states are known to be dominated by the $\pi(h_{9/2}i_{13/2})$ orbitals in the ^{198,200}Po isotopes [2, 3, 8]. A theoretical study on seniority isomers in Pb ($Z = 82$) and Hg ($Z = 80$, *i.e.* two-proton hole) isotopes [10] predicted seniority to be a nearly good quantum number in Po ($Z = 84$, *i.e.* two-proton particle) isotopes as well and suggested $N = 118$ to be a transition region which needs further investigations to understand the behaviour of these nuclei around the $Z = 82$ shell closure.

We investigate the ^{202}Po ($N = 118$) nucleus to understand the two-particle case above $Z = 82$ shell closure at the $N = 118$ transition region. High-spin states of ^{202}Po were last established by Fant *et al.* [2] with the highest tentatively assigned spin being (22^+). The low-medium spin states up to (9^-) were explored by Bijnens *et al.* [4] in 1998, via β-decay studies of ^{202}At. The half-life of the yrast 11^- state in ^{202}Po was measured as 85(10) ns by Häusser *et al.* [8] in 1976, 100(50) ns by Beuscher *et al.* [3] in 1976, and > 200 ns by Fant *et al.* [2] in 1990. The half-life of the 8^+ isomeric state was reported as 110(15) ns by Häusser *et al.* [8], 85(15) ns by Beuscher *et al.* [3], and 85(15) ns by Fant *et al.* [2]. The present work reports improved measurements of the half-lives for the 8^+ and 11^- isomeric states in the $N = 118$ ^{202}Po isotope, using the electronic timing of high-purity germanium (HPGe) detectors. Such measurements are crucial for getting the information on nuclear structural wavefunctions and corresponding neutron and proton pair break-ups.

2. Experimental details and data analysis

High-spin states of the ^{202}Po nucleus were populated using ^{195}Pt(^{12}C, $5n$) reaction. The ^{12}C beam, accelerated to 83 MeV by the 14-UD Pelletron LINAC facility at the Tata Institute of Fundamental Research, Mumbai, bombarded a 3.2 mg/cm^2 thick ^{195}Pt target with a ^{197}Au catcher foil. The

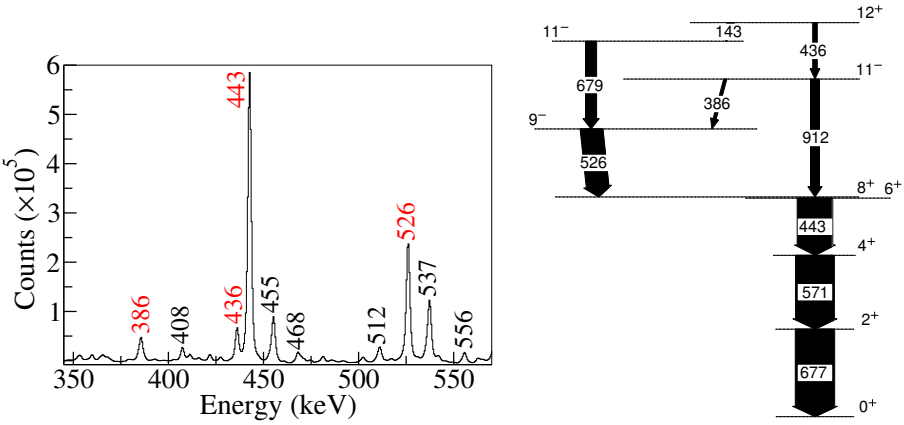
de-exciting γ rays were detected using an array of 16 Compton-suppressed HPGe clover detectors at 23°, 40°, 65°, and 90° with respect to the beam direction. Two- and higher-fold coincidence data were collected in a list-mode format using an XIA-based digital data-acquisition system [11, 12]. After the energy calibration of all the HPGe detectors, the time-stamped coincidence data were sorted using the Multi pARameter timestamped based COincidence Search (MARCOS) code, developed at TIFR, Mumbai [11]. The γ–γ matrices and γ–γ–γ cubes were formed and analysed using DAMM [13] and RADWARE [14] software packages.

Lifetimes of the isomeric states were determined by the decay slope method using the electronic timing of the HPGe clovers. The decay half-lives ($T_{1/2}$) for the states were extracted using the time-difference spectrum between two transitions $E_{\gamma 1}$ and $E_{\gamma 2}$ in a cascade, feeding and de-exciting the state of interest, respectively. To obtain the time-difference spectrum, four conditional time spectra, $t_{\mathrm{p1,p2}}$, $t_{\mathrm{p1,bg2}}$, $t_{\mathrm{bg1,p2}}$, and $t_{\mathrm{bg1,bg2}}$, were generated from the time-stamped data. Here, $t_{\mathrm{p1,p2}}$ represents the time-difference spectrum obtained with energy gates around the $E_{\gamma 1}$ and $E_{\gamma 2}$ peaks, while $t_{\mathrm{p1,bg2}}$ represents the same for energy gates around the $E_{\gamma 1}$ peak and background near the $E_{\gamma 2}$ peak. Similarly, $t_{\mathrm{bg1,p2}}$ and $t_{\mathrm{bg1,bg2}}$ correspond to energy gates on $E_{\gamma 1}$ background — $E_{\gamma 2}$ peak and $E_{\gamma 1}$ background — $E_{\gamma 2}$ background, respectively. Then the final time-difference spectrum was generated as follows: $t = t_{\mathrm{p1,p2}} - t_{\mathrm{p1,bg2}} - t_{\mathrm{bg1,p2}} + t_{\mathrm{bg1,bg2}}$ [11, 15]. The half-lives of the states were extracted by fitting the time-difference spectra with a convoluted Gaussian and an exponential function considering the detector response function as explained in Ref. [15].

3. Results

The previously known level scheme of ^{202}Po [2] has been confirmed and substantially extended up to $J^\pi = 27^+$; with the addition of 45 new transitions, a more elaborate article is in preparation [16]. The γ-ray energy spectrum obtained by gating on the 571+677 keV transitions in the HPGe clovers is shown in Fig. 1 (a). The gated γ-ray energy spectrum and the partial level scheme shown in Fig. 1 depict the transitions feeding and de-exciting the yrast 8^+ and 11^- isomeric states.

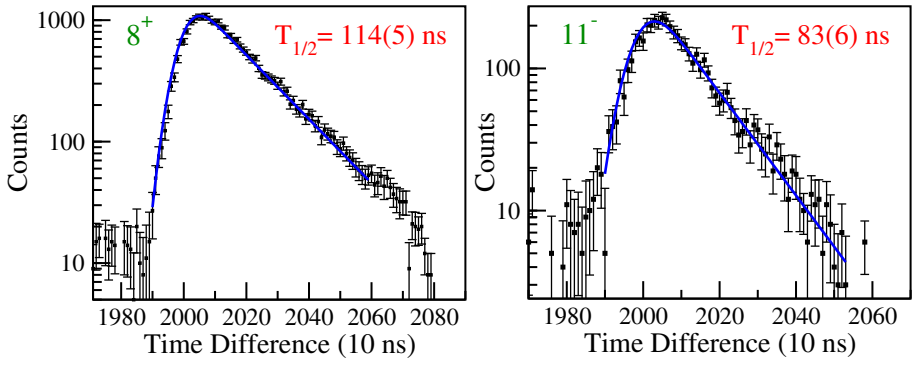
The decay half-life ($T_{1/2}$) for the 8^+ isomeric state was extracted using the time-difference spectrum between the two transitions $E_{\gamma 1} = 526$ keV (feeding) and $E_{\gamma 2} = 443$ keV (decaying) in the cascade. For the 11^- isomeric state, $T_{1/2}$ was extracted using the time-difference spectrum between the two transitions $E_{\gamma 1} = 436$ keV and $E_{\gamma 2} = 386$ keV in the cascade. To avoid contaminations, the time-difference spectra were obtained by gating the γ–γ matrix on the 677 keV transition. Figure 2 shows the time-difference spectra for the 8^+ and 11^- states along with the fits of the data using a convoluted



(a) (b)

Fig. 1. (a) Gamma-ray energy spectrum gated on the 571+677 keV transitions, showing the transitions feeding and de-exciting the 8^+ and 11^- isomeric states. (b) Partial level scheme of ^{202}Po showing the two isomeric states and their feeding and decaying transitions.

Gaussian and exponential function. The improved decay half-lives of the yrast 8^+ and 11^- isomeric states have been found to be $T_{1/2}(8^+) = 114 \pm 5$ ns and $T_{1/2}(11^-) = 83 \pm 6$ ns. Since the decay from the 8^+ isomeric state to the 6^+ state could not be observed, the energy of the $8^+ \rightarrow 6^+$ transition



(a) (b)

Fig. 2. (Colour on-line) Time-difference spectrum generated using (a) 526 and 443 keV transitions feeding and de-exciting the 8^+ isomeric state, respectively (black). (b) 436 and 386 keV transitions feeding and de-exciting the 11^- isomeric state, respectively (black). The fits (solid blue) of the selected region by a convoluted Gaussian and exponential function provide the $T_{1/2}$ of the two isomeric states.

was obtained to be 9.0(3) keV via a newly observed transition bypassing the 8^+ isomeric state, which will be discussed in a forthcoming article [16]. The $B(\mathrm{E2};\ 8^+ \rightarrow 6^+)$ value in ^{202}Po was calculated using this decay energy.

4. Discussion

We study the evolution of isomeric transition probabilities with respect to neutron (Figs. 3 (a), 4 (a)) and proton number (Figs. 3 (b), 4 (b)) to understand empirically the competition of single-particle nature and collectivity in ^{202}Po. The 8^+ isomeric states in even–even nuclei above the $Z = 82$ shell closure are mainly dominated by the $\pi(h_{9/2})$ orbital with a limited mixing of the neighboring $f_{7/2} \otimes i_{13/2}$ orbitals [17]. Figure 3 (a) shows the systematic behavior of the $B(\mathrm{E2})$ values for this proton isomer in even–even Po isotopes with $N = 114$–128. Since the isomeric configuration is dominated by protons, the $B(\mathrm{E2})$ values remain nearly constant with neutron number, with a slight increment when moving away from the $N = 126$ shell closure. This may be attributed to a stronger coupling between the two protons and a surface vibration in the Po isotopes [9]. We present the evolution of $B(\mathrm{E2})$ values in the decay of the proton-dominated 8^+ isomeric states for various isotonic chains in Fig. 3 (b). The generalized seniority approach has recently been used to explain its parabolic behavior in $N = 124$, 126 chains [17]. One can see that the $B(\mathrm{E2};\ 8^+ \rightarrow 6^+)$ value for ^{202}Po (present work) is very similar to the $B(\mathrm{E2};\ 8^+ \rightarrow 6^+)$ value for ^{208}Po (with $N = 124$), while the $B(\mathrm{E2};\ 8^+ \rightarrow 6^+)$ value in ^{200}Po (with $N = 116$) is higher. This suggests that the 8^+ isomeric states have a predominantly single-particle nature and the one in ^{202}Po can be referred to as a seniority isomer. However, there are

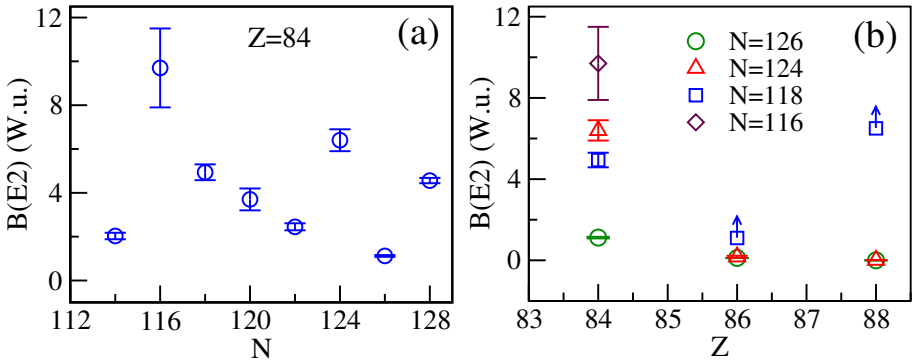


Fig. 3. $B(\mathrm{E2})$ values for the decay of the 8^+ isomeric states in (a) Po isotopes, (b) even–even $N = 116$, 118, 124, 126 isotones above the $Z = 82$ shell closure. The $B(\mathrm{E2})$ value for $N = 118$, $Z = 84$ is from the present work. All other $B(\mathrm{E2})$ values are taken from Ref. [18].

only lower limits of $B(\mathrm{E2};\ 8^+ \rightarrow 6^+)$ values known in $N = 118$ isotones with $Z = 86$ and $Z = 88$, making them good candidates for future measurements to decipher the evolution of these isomers in the $N = 118$ isotonic chain.

Figure 4 (a) shows the systematics of $B(\mathrm{E3})$ values in the decay of the 11^- isomeric states in even–even Po isotopes with $N = 112$–126. The 11^- state in ^{202}Po is similar to the 11^- state in ^{208,210}Po and can be interpreted as the $\pi(h_{9/2}i_{13/2})$ state [3]. The increasing trend in the $B(\mathrm{E3};\ 11^- \rightarrow 8^+)$ values when moving away from the $N = 126$ shell closure can be attributed to a weak-coupling to the core polarization and a wave function spread with the neighboring $h_{9/2}$ and $f_{7/2}$ orbitals. This can be taken as a signature of increased collectivity when going away from $N = 126$. We plot in Fig. 4 (b) the $B(\mathrm{E3};\ 11^- \rightarrow 8^+)$ evolution with proton number for the proton-dominated 11^- isomeric states in various isotonic chains above $Z = 82$. The measured $B(\mathrm{E3})$ value for the decay of this isomeric state at $Z = 84$, $N = 118$ overlaps, within the error bar, with the measurement for $Z = 84$, $N = 124$. This again points to a single-particle nature of this two-proton-dominated isomeric state, though $N = 118$ is quite far from the closed shell. Similar measurements looking for E3 isomers in the $N = 118$ isotonic chain at $Z = 86$, 88 would be interesting to understand the structural evolution.

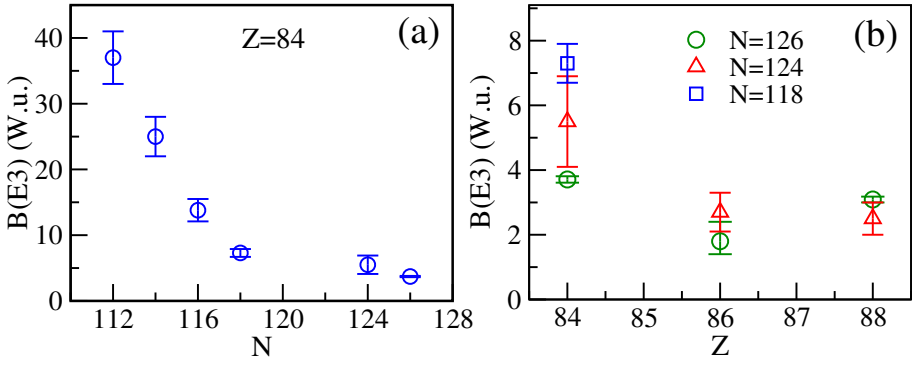


Fig. 4. $B(\mathrm{E3})$ values for the decay of the 11^- isomeric states in (a) Po isotopes, (b) even–even $N = 118$, 124, 126 isotones above the $Z = 82$ shell closure. The $B(\mathrm{E3})$ value for $N = 118$, $Z = 84$ is from the present work. All other $B(\mathrm{E3})$ values are taken from Ref. [18].

5. Summary

Improved half-lives of the proton isomers 8^+ and 11^- have been obtained by the decay slope method using HPGe clover detectors. A systematic study of the $B(\mathrm{E2};\ 8^+ \rightarrow 6^+)$ and $B(\mathrm{E3};\ 11^- \rightarrow 8^+)$ values in the decay of isomeric states in the even–even Po isotopes with $N = 112$–126 indicates a higher mixing of configurations when moving away from the $N = 126$ shell

closure and an increasing competition between the single-particle nature and collectivity. Systematics of the reduced transition probabilities in the decay of these isomeric states has also been presented for even–even $N = 116$, 118, 124, 126 isotonic chains to understand the evolution of these proton-dominated isomers.

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