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Short note

High spin states above the α-decaying isomer in ^{211}Po

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Abstract. Prompt and delayed γ-rays in nuclei of the ^{208}Pb region produced in 450 MeV ^{76}Ge + ^{208}Pb collisions have been studied at GASP. Yrast states above the α-decaying isomer in ^{211}Po have been located including a 0.25 μs $31/2^-$ isomer at 2135 keV and a 2 μs isomer at 4874 keV.

PACS. 21.60.Cs Shell model – 23.20.Lv Gamma transitions and level energies – 27.80.+w $190 \leq A \leq 219$ – 25.70.Lm Strongly damped collisions

The 25.2 s α-decaying state with $I^\pi=25/2^+$ at 1462 keV in ^{211}Po is one of the classic examples of yrast "spin-gap" isomers in nuclei. Many years ago, Auerbach and Talmi [1] demonstrated that in this three-particle nucleus the $(\pi h^2_{9/2}\nu g_{9/2})25/2^+$ level lies below the $19/2^+$, $21/2^+$, and $23/2^+$ multiplet members because the $\pi h_{9/2}\nu g_{9/2}$ proton-neutron attraction is significantly stronger in the maximally aligned J=9 coupling than in the states with J=8,7,6,5 or 4. The level structure of ^{211}Po is not accessible for study by heavy-ion induced fusion-evaporation reactions, and only lower spin levels up to the 1462 keV isomer have been located in ^{211}Bi β^- decay and in ^{208}Pb$(\alpha,n\gamma)^{211}$Po investigations [2]. Warburton [3] has performed shell model calculations for ^{211}Po using modified Kuo-Herling nucleon-nucleon interactions, and the results agree rather well with the experimental level spectrum up to the $25/2^+$ isomer. These calculations also predict higher lying $27/2^+$, $31/2^-$, $33/2^-$ and $37/2^+$ yrast states that should decay by γ-ray cascades feeding the $25/2^+$ isomeric state. In the present work we have investigated the yrast excitations of ^{211}Po above the 25.2 s isomer using heavy-ion induced few-nucleon transfer reactions.

In a series of recent experiments we have shown that the yrast spectroscopy of nuclei which are not accessible in standard heavy-ion fusion-evaporation reactions, can be studied very successfully in heavy-ion multinucleon transfer processes (~15% above Coulomb barrier), using γ-γ thick target technique [4,5]. In one of these studies we used the ^{76}Ge+^{208}Pb reaction to populate products in vicinity of ^{208}Pb [6]. The experiment was performed at the Legnaro linear accelerator ALPI using pulsed beam of 450 MeV ^{76}Ge ions on a target of 50 mg/cm^2 ^{208}Pb. The time spacing between beam bursts was 400 ns. Gamma-rays were detected with the GASP array, which consists of 40 Compton-suppressed Ge detectors and an inner BGO ball of 80 elements. The data were recorded event by event with a trigger requiring prompt firing of at least two Ge detectors. Each event stored Ge energy with timing information and the γ - RF time. Conditions set on the γ-RF and γ-γ time parameter were used to obtain the prompt, off-beam as well as prompt-delayed γ-γ matrices.

Known high spin γ-rays in the neutron-rich Pb, Bi, Po, At nuclei were clearly observed in the data and analysis of the product yield distribution indicated that also in ^{211}Po the higher spin states should be populated.

In the N=126 nucleus ^{210}Po the level structure at low energies is dominated by the proton $h^2_{9/2}$ seniority-2 multiplet up to the isomeric 8^+ state at 1557 keV. The next yrast excitation above the 8^+ isomer is the $(\pi h_{9/2} i_{13/2})11^-$ state, which is also isomeric, decaying by two E3 transitions. Other known yrast isomers in ^{210}Po above 4 MeV have I^π values of 13^- and 16^+ and are interpreted as core-excited states of $(\pi h^2_{9/2})8^+\times5^-$ and $(\pi h_{9/2} i_{13/2})11^-\times5^-$ character involving the $(\nu g_{9/2} p^{-1}_{1/2})5^-$ particle-hole excitation. Turning now to the N=127 ^{211}Po nucleus with one additional valence neutron, one may expect low-lying multiplets arising from coupling of the $\pi h^2_{9/2}$ and $\pi h_{9/2} i_{13/2}$ configurations to the $\nu g_{9/2}$ neutron, with highest spin members $25/2^+$

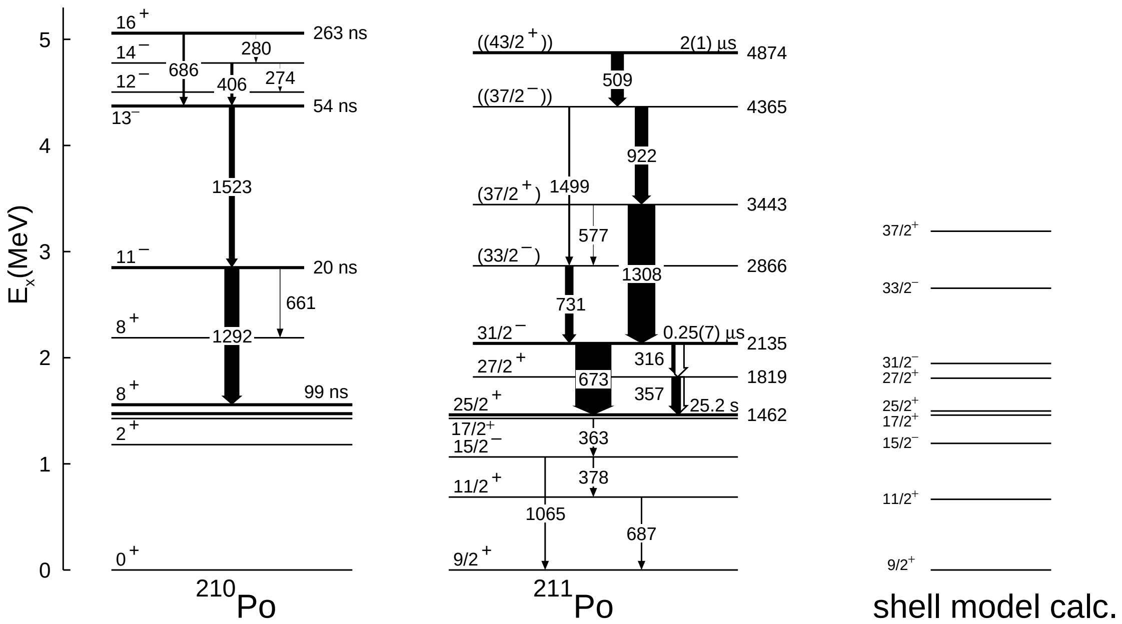

Fig. 1. Partial level scheme of ^{210}Po and the yrast level spectra established for ^{211}Po. *Arrow widths* denote the relative γ-ray intensities observed in prompt-delayed coincidence with the 673 keV transition. Results of the shell model calculations from [3] are also shown

and $31/2^-$, respectively. Further, one could expect an isomeric $31/2^-\rightarrow 25/2^+$ E3 transition in ^{211}Po analogous to the ^{210}Po $11^-\rightarrow 8^+$ E3.

We searched for this ^{211}Po $31/2^-\rightarrow 25/2^+$ transition in the $\gamma\gamma$ prompt-delayed coincidence matrix from the ^{76}Ge + ^{208}Pb reaction by examining the cross coincidence relationship between complementary Po and Zn reaction products. Gates were set on prompt γ-rays in ^{72}Zn, ^{70}Zn, and ^{68}Zn, and delayed γ-rays de-exciting isomeric states with 10-500 ns half-lives in Po partner nuclei were displayed. These delayed transitions included known γ-rays from several Po isotopes as well as a prominent 673 keV γ-ray not known previously. The intensity pattern of prompt transitions from $^{68-72}$Zn isotopes observed in coincidence with the delayed 673 keV line indicated clearly that this γ-ray occurs in the ^{211}Po nucleus, and is thus very likely to be the sought for $31/2^-\rightarrow 25/2^+$ transition. No gamma-rays appeared in prompt coincidence with the 673 keV γ-ray, but 316 and 357 keV γ-rays in cascade parallel to the 673 keV transition were subsequently found. The 316 keV γ-ray intensity was observed to be about 2.5 times lower than that of the 357 keV γ-ray; intensity balance requirements point towards M2 character for the 357 keV transition ($\alpha_{tot}\sim 2.0$), with M1 for the 357 keV transition ($\alpha_{tot}\sim 0.3$). These results locate an intermediate level at 1819 keV with I$^\pi$=27/2$^+$, which almost certainly corresponds to the $(\pi h^2_{9/2}\nu i_{11/2})27/2^+$ predicted at about this energy in shell model calculations.

A gate on the delayed 673 keV γ-ray exhibited, in addition to γ-rays from the Zn reaction partners, a group of transitions with energies 1308, 922, 509, 731, and 1499 keV, which were thus identified as ^{211}Po γ-rays preceding the $31/2^-$ isomer. By detailed examination of the coincidence data, new states were located at 2866, 3443, 4365, and 4874 keV excitation energy, of which the highest is an isomer with $T_{1/2}$ = 2$\pm$1 μs. The partial level scheme of ^{211}Po is shown in Fig. 1. Analysis of the $T_{\gamma\gamma}$ time distributions between the 673 keV γ-ray and the strong transitions preceding that γ-ray (1308, 922, 509 keV) yielded the value $T_{1/2}$ = 0.25(7) μs for the $31/2^-$ state. Calculation of the B(E3) for the 673 keV transition, taking into account the 316 keV branching, gives B(E3; $31/2^-\rightarrow 25/2^+$) = 57(15)$\times 10^3$ e^{2}fm^6, or 22(6) W.u.

Warburton's shell model calculations in the Kuo-Herling model space [3] predict the $31/2^-$ yrast level at 498 keV above the $25/2^+$ isomer, with the $(\pi h^2_{9/2}\nu i_{11/2})27/2^+$ level in between, as was found in the present experiment. The same calculations give only two yrast states above the $31/2^-$ isomer: a $33/2^-$ level at 2655 keV arising from the $\pi h_{9/2} i_{13/2}\times\nu i_{11/2}$ coupling, and a $37/2^+$ state at 3192 keV of $\pi h_{9/2} i_{13/2}\times\nu j_{15/2}$ type. Both states should decay to the $31/2^-$ isomer by M1 and E3 transitions, respectively. The levels placed in this work at 2866 keV and 3443 keV, decaying to the $31/2^-$ isomer by 731 keV and 1308 keV transitions are probably these $33/2^-$ and $37/2^+$ excitations.

The two highest states located at 4365 and 4874 keV must involve excitation of the ^{208}Pb core. The 4365 keV level decaying by 1499 keV and 922 keV γ-rays to the $33/2^-$ and $37/2^+$ states is very likely to have I$^\pi$=37/2$^-$. The high-lying isomer at 4874 keV decays with a half-life of about 2 μs by a 509 keV transition to the 4365 keV ($37/2^-$) level. The 509 keV transition is probably of E3 character, and is a counterpart of the 686 keV E3 connecting the 16^+ and 13^- states in ^{210}Po. Accordingly, we tentatively assign I$^\pi$=43/2$^+$ to the 4874 keV ^{211}Po isomer, and interpret the $(37/2^-)$ and $(43/2^+)$ levels as $(\pi h^2_{9/2} \nu i_{11/2}) 27/2^+ \times 5^-$ and $(\pi h_{9/2} i_{13/2} \nu i_{11/2}) 33/2^- \times 5^-$ core excited states with support from simple shell model calculations using empirical single particle energies and nucleon-nucleon interactions.

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