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The $\pi h^{-1}_{11/2}\nu i^{-2}_{13/2}$ three-hole isomeric state and octupole core excitation in the ^{205}Tl nucleus

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Abstract. New high-spin states were identified in the ^{205}Tl isotope produced in deep-inelastic heavy-ion reactions. The expected $29/2^+$ yrast state and $35/2^-$ isomeric state with 235 ns half-life were located above the 2.6 μs isomer known from previous studies. Above this isomer a 7092 keV level was interpreted as a $41/2^+$ state arising from the coupling of the octupole vibration of the ^{208}Pb core with the three-hole structure of the $35/2^-$ isomer.

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

High-spin state study of nuclei that are not accessible in standard fusion reactions can be performed by employing complex deep-inelastic heavy-ion reactions in which many of such nuclei are produced with satisfactory population of high-spin states. The review of this type of investigations using large multidetector gamma arrays was presented by R. Broda *et al.* [1] at this conference and included also a number of results obtained in the yrast spectroscopy study of nuclei from the ^{208}Pb region. In a long series of experiments a variety of heavy-ion beams of ^{48}Ca, ^{64}Ni, ^{76}Ge, ^{82}Se, ^{136}Xe and ^{208}Pb bombarding a thick ^{208}Pb target were used and the high-quality gamma coincidence data were analyzed focusing on the spectroscopy of selected nuclei. Among many nuclei produced in such reactions the data also include heavy Tl isotopes for which only a fragmentary knowledge of the high-spin state structure was available. The earlier analysis established already new yrast structures in the ^{206}Tl and ^{207}Tl as reported by M. Rejmund [2]. The present work describes preliminary results of the most recent analysis which concentrated on high-spin states of the ^{205}Tl isotope. Yrast states of the ^{205}Tl up to the 2.6 μs $25/2^+$ isomer were known from the earlier gamma spectroscopy study [3]; however, higher-spin states above the isomer remained hitherto unobserved. Simple considerations allow to anticipate a clear continuation of the yrast line above this three-hole $\pi h^{-1}_{11/2}\nu p^{-1}_{1/2}i^{-1}_{13/2}$ isomeric state, when the $p_{1/2}$ neutron hole is replaced by the next available $f_{5/2}$ and $i_{13/2}$ holes. The maximum spin coupling of $29/2^+$ and $35/2^-$ of these holes with the remaining proton and neutron holes is energetically favored and strong population of such states in the yrast cascade is naturally expected. Moreover, the upper state arising from the proton $\pi h^{-1}_{11/2}\nu i^{-2}_{13/2}$ configuration is likely to be isomeric in analogy to the $(i^{-2}_{13/2})12^+$ 202 ns isomer, in ^{206}Pb which decays via $E3$ (1369 keV) and $E2$ (458 keV) transition cascade to the long-lived 7^- isomer. Of all available data the best set selected for the ^{205}Tl case analysis came from the ^{48}Ca(305 MeV) $+^{208}$Pb experiment which was performed using the GAMMASPHERE array at the Argonne NL. The unambiguous identification of higher-lying states in ^{205}Tl was provided by the analysis of delayed coincidence events selecting appropriate gates on the $T_{\gamma\gamma}$ parameter. Figure 1 shows the level scheme established for ^{205}Tl and gamma coincidence spectra illustrating identification and placement of new transitions. The spectrum shown in insert a), obtained by gating on the delayed 506 keV transition below the $25/2^+$ 2.6 μs isomer in ^{205}Tl shows two strong lines of 328 and 1217 keV energy, which apparently precede in time the isomer and match perfectly the expected transitions in analogy to the above-mentioned 458–1369 keV cascade in ^{206}Pb. The observed intensities clearly locate the 1217 keV transition above the more intense 328 keV transition. The reversed time gate set on the 1217 keV preceding line gave the delayed gamma spectrum

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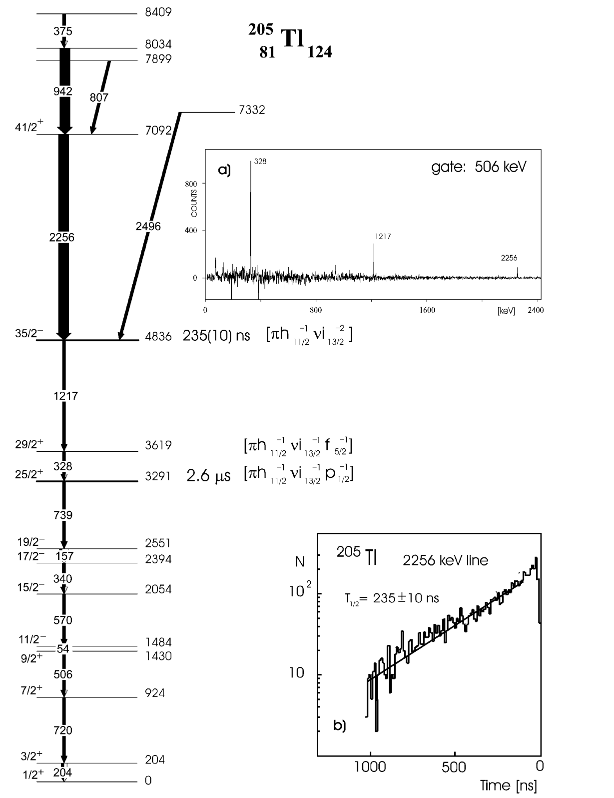

Fig. 1. ^{205}Tl level scheme. a) Gamma spectrum preceding the 2.6 μs isomer, b) lifetime determination.

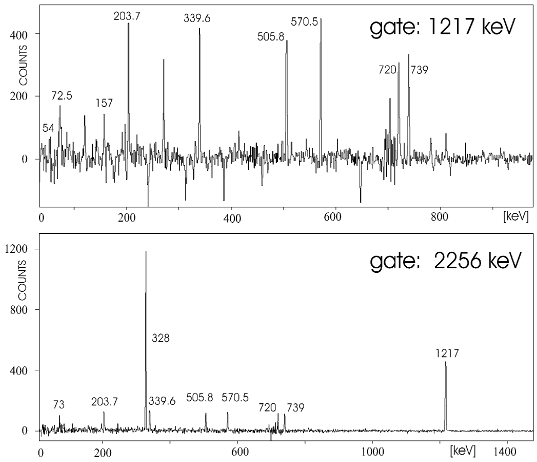

Fig. 2. Delayed gamma coincidence spectra.

shown as upper spectrum of fig. 2. The appearance of all strong transitions occurring in the 2.6 μs isomer decay in ^{205}Tl proves uniquely the identification. Also, in agreement with expectations, both 328 and 1217 keV transitions were found to be delayed in time, indicating the existence of a new isomer. Analysis of coincidences with delayed 328 and 1217 keV gates revealed many transitions located above this new isomer and among them the most intense line of 2256 keV focused our special attention, as will be discussed in the following. The gate set on this 2256 keV line gave a transparent delayed gamma spectrum shown in the lower panel of fig. 2 with two strong lines from the decay of the new isomer and naturally much weaker lines occurring in the long-lived lower isomer decay. The time spectrum shown in fig. 1 for appropriately selected coincidence events provided fairly accurate half-life determination of 235(10) ns for the new isomer. This value is reasonably close to the half-life value of the ^{206}Pb 12^+ isomer and consequently the presently observed 1217 keV in ^{205}Tl is very likely to be an analogous transition to the 1369 keV slow $E3$ isomeric transition in ^{206}Pb. In both cases, the $B(E3)$ transition probability must be governed by admixtures of other configurations to the main structure involving strongly forbidden $i_{13/2} \rightarrow f_{5/2}$ $E3$ transition. The level scheme presented in fig. 1 indicates configurations assigned to the new states basing on the above outlined expectations and analogy to ^{206}Pb states. The higher part of the level scheme above the 235 ns isomer is still preliminary and far from complete; however, the most intense 2256 keV transition feeding the isomer reminds us very much of the fast $E3$ yrast transition observed abundantly in many other nuclei in the ^{208}Pb region. A detailed discussion of the coupling of octupole vibrations of the ^{208}Pb core with simple shell model high-spin states in neighboring nuclei was presented in ref. [4] and the review of many observed cases was presented at this conference [1]. It is tempting to assign the 7092 keV level which decays by the 2256 keV transition as the $41/2^+$ state arising from the maximum spin coupling of the $35/2^-$ isomeric state with $E3$ excitation of the core. Here, one has a clear-cut situation where the valence three holes $\pi h^{-1}_{11/2}\nu i^{-2}_{13/2}$ couple to maximum spin and the stretched coupling of the 3^- core excitation is the best way to acquire a higher-spin value; strong population of the 7092 keV state indicates such prominent yrast character. As demonstrated earlier [1,4], the energy shift of such excitation compared to the unperturbed octupole excitation 2615 keV energy should be reproduced by straight addition of experimentally observed energy shifts for $E3$ excitation built on individual more simple states. The addition of $\Delta E = -150$ keV resulting from 2465 keV $E3$ known above the $h_{11/2}$ proton hole state in ^{207}Tl and $\Delta E = -212$ keV from 2403 keV $E3$ above the $(i^{-2}_{13/2})12^+$ state in ^{206}Pb gives the total energy shift of $\Delta E = -362$ keV for the complex $(\pi h^{-1}_{11/2}\nu i^{-2}_{13/2})35/2^-$ state in ^{205}Tl. This gives the 2253 keV energy for the $E3$ excitation in spectacular agreement with the 2256 keV experimental value and provides strong support for the suggested interpretation. Future independent confirmation of spin-parity assignments could be an important demonstration of the validity of the simple additivity rule observed for the particle-octupole vibration coupling in the ^{208}Pb region.

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