Nanosecond isomers in ^{204}Pb

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Introduction

Nuclear isomers are metastable states resulting from hindrances in the de-excitation process of certain nuclear levels. These hindrances can arise from significant changes in spin, shape, or angular momentum projection between neighboring energy levels. Quantum mechanically, substantial differences in the wavefunctions of adjacent levels can lead to isomerism, often resulting in differences in decay rates compared to non-isomeric transitions. Studying these isomeric states is vital for understanding nuclear phenomena and the interactions that shape nuclear structure. Moreover, isomeric properties contribute significantly to improving effective interactions used in shell-model calculations for near-spherical nuclei, providing deeper insights into the underlying nuclear behavior and structure in specific regions of the nuclear chart [1].

The presence of high-j proton and neutron orbitals near the doubly-magic ^{208}Pb provides a fertile region to explore nuclear isomerism. Our previous work [2–6] in this region also shows the rich presence of isomeric levels with halflives ranging from nanoseconds up to hundreds of microseconds at low to very high excitation energies. The current work is an exploration of short-lived nanosecond isomeric states in ^{204}Pb.

Experiment

In the previous work on ^{204}Pb [7], the prompt yrast cascade up to 8.1 MeV had been established utilizing α particles incident on ^{204}Hg targets. All the prompt γ rays up to the level at 8126 keV were found to be feeding the previously known isomeric 9^- level with $T_{1/2} = 66.93(10)$ min at 2186 keV. Spins and parities were established for levels up to the 19^- level at 6097 keV.

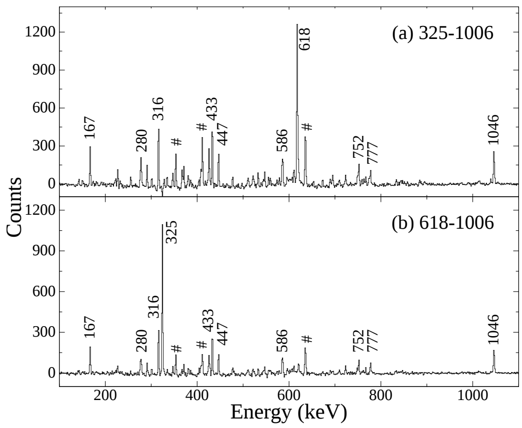

FIG. 1: Coincidence spectra with simultaneous gates on the indicated transition energies in ^{204}Pb. Hash marks designate contaminant γ rays.

In the present work, the ^{204}Pb nucleus was populated up to quite high spins using highly-energetic, heavy beam and target combinations in two experiments. Multi-nucleon transfer reactions between a 1450-MeV ^{209}Bi and a 1430-MeV ^{207}Pb beam, from the ATLAS accelerator at the Argonne National Laboratory and a thick target of ^{197}Au were studied. Three- and higher-fold γ-ray coincidence data were recorded using the Gammasphere detector array which comprised of 100 High-Purity Germanium (HPGe) detectors. The data were sorted into a number of different histograms [8] and analyzed using the Radware suite of programs [9].

Results and Discussion

The high-spin structure of ^{204}Pb had already been reported up to 8 MeV [7]; the

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placement of the transitions was verified in our previous work [1]. The transitions above the isomeric 9^- level with $T_{1/2} = 66.93(10)$ min are shown in the coincidence spectra (FIG. 1) demonstrating the significant population of the yrast levels in ^{204}Pb. No previous isomeric information was known on any of these yrast levels found above the isomeric 9^- level except the long-lived state reported in our earlier work [1]. Detailed information on low-lying two-neutron-hole configurations in even-A Pb isotopes are known for the $[\nu(i_{13/2})^{-1} \otimes \nu(p_{1/2})^{-1}]$ $[\nu(i_{13/2})^{-1} \otimes \nu(f_{5/2})^{-1}]$ and $[\nu(i_{13/2})^{-2}]$ configurations, leading to the realization of isomeric $I^\pi = 7^-$, 9^-, and 12^+ states [7, 10]. There is rather sparse experimental isomeric information on states with spin higher than $12\hbar$ (*i.e.*, with more than two-quasiparticle excitations) in this region.

In both ^{202}Pb and ^{206}Pb, the 12^+ states are known to be isomeric, prompting us to study the time difference spectra across the 12^+ state and other yrast levels in ^{204}Pb. To establish the half-life of the $I^\pi = 12^+$ state in ^{204}Pb, which had not been reported earlier, the difference in time of the γ rays feeding and de-exciting this level (618 and 325 keV, respectively) was plotted and compared with that of prompt transitions of similar energy. Additionally, the time difference between the 433-keV γ ray feeding and the 316-keV de-exciting transition was measured to determine the half-life of the $I^\pi = 17^-$ state. Both the 12^+ and 17^- states were found to be isomeric with halflives of a few nanoseconds.

The systematics of the two-neutron-hole isomeric states $[\nu({f_{5/2}}^{-1}, {i_{13/2}}^{-1})]_{9^-}$ and $[(i_{13/2})^{-2}]_{12^+}$ in the even-Pb isotopes have also been studied in this work. The decay of the nanosecond isomeric 17^- state via a large $E1$ transition, similar to that of the 12^+ isomeric state, indicates involvement of high-j orbitals in its configuration. Further analysis and justification for the configuration assignments of 4-neuton-hole and 2-neutron-hole states in ^{204}Pb, along with halflife plots would be presented at the symposium.

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References

[1] S.G. Wahid, et al., Phys. Lett. B 832 (2022) 137262.
[2] S.G. Wahid, et al., Phys. Rev. C 102 (2020) 024329.
[3] Poulomi Roy, et al., Phys. Rev. C 100 (2019) 024320.
[4] V. Bothe, et al., Phys. Rev. C 105 (2022) 04432.
[5] Saket Suman, et al., Phys. Rev. C 103 (2021) 014319.
[6] Saket Suman, et al., Phys. Rev. C 106 (2022) 024316.
[7] C.G. Linden, et al., Z. Physik A 284, 217 (1978).
[8] S.K. Tandel, et al., Phys. Lett. B 750 (2015) 225.
[9] D.C. Radford, Nucl. Instrum. Methods A 361 (1995) 297.
[10] R. Lutter, et al., Nucl. Phys. A229 (1974) 230.