# Novel shapes and symmetries in heavy nuclei

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## Introduction

The strong interaction which binds nucleons in a nucleus is not as well understood as other fundamental interactions. The study of novel aspects of nuclear structure leads to insights into the nature of the strong interaction and therefore contributes to a fundamental understanding of the constituents of matter and their interactions. This thesis work is focused on the structure of nuclei near doubly magic $^{208}$Pb. Unusual shape transitions are predicted in neutron-rich Pt isotopes. Oblate states based on rotation-aligned configurations are expected to be favoured in contrast to the more usual preference for prolate shapes at high spin. Single-particle excitations are the favoured mode of excitation in near-spherical nuclei; the study of excited states can thereby provide information about the ordering and relative spacing of single-particle levels. The presence of high-$j$ $\nu i_{13/2}$ and $\pi h_{11/2}$ orbitals in nuclei below $^{208}$Pb make it possible to realize high-spin isomers with predominantly intrinsic character, which yield essential information about single-particle, pairing and residual interaction energies, essential inputs for a detailed understanding of nuclear structure. It is quite difficult to populate and study excited levels at high spin in these nuclei using conventional fusion-evaporation reactions; multi-nucleon transfer or projectile fragmentation reactions are more suitable. These typically produce a large number of isotopes and consequently an enormous number of $\gamma$ rays therefore complex data analysis techniques have to be employed.

## Experiment and Analysis

Two sets of experiments were performed, one using the INGA array comprising 14 Compton-suppressed clover HPGe detectors and one planar HPGe detector at the Inter-University Accelerator Centre, New Delhi, and the other measurement was at Argonne National Laboratory, USA, using the Gammasphere array consisting of 100 HPGe detectors. These two data sets are complementary to each other. The INGA experiment was carried out to populate high spin in $^{202}$Tl using the $^{7}$Li($^{198}$Pt, 3n)$^{202}$Tl reaction with an enriched $^{198}$Pt target. Excited states in various Pt, Tl and Pb isotopes were populated via multi-nucleon transfer among $^{209}$Bi and $^{207}$Pb beams from the ATLAS accelerator at Argonne which were incident on a $^{197}$Au target. Details about the data analysis techniques employed may be found in our earlier work [1, 2]. The IPDCO analysis and information on low-energy transitions were obtained from the INGA data. The Gammasphere data were particularly useful in the case of long-lived isomers.

## Results and Discussion

In the present work, the high-spin structure of $^{192-198}$Pt, $^{202}$Tl and $^{203}$Pb nuclei has been extensively explored. Rotational aligned sequences, built on $I^{\pi} = 33/2^{+}$ and $12^{+}$ states have been established in $^{195}$Pt and $^{196}$Pt, respectively, for the first time. Several new transitions are established at high spin in other even and odd Pt isotopes. The $I^{\pi} = 12^{+}$ state in $^{196}$Pt and $I^{\pi} = 33/2^{+}$ state in $^{195}$Pt are found to be isomeric with $T_{1/2} = 7.7(7)$ns and 5.5(5) ns respectively. New high spin isomers in $^{202}$Tl: $I^{\pi} = (20^{+})$ and $^{203}$Pb: $I^{\pi} = 37/2^{+}$

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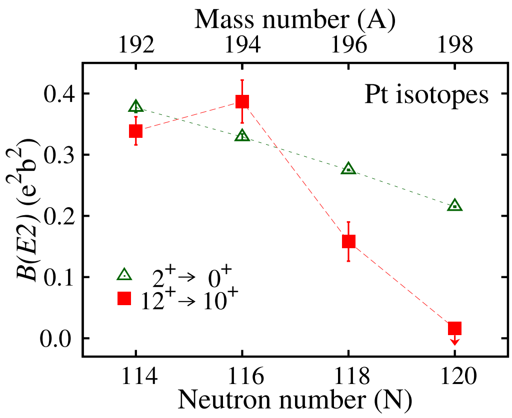


FIG. 1: Reduced $E2$ transition probabilities for $2^+ \rightarrow 0^+$ and $12^+ \rightarrow 10^+$ transitions in even Pt isotopes.

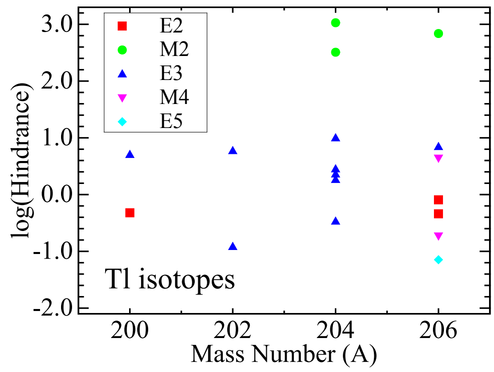


FIG. 2: Hindrances for isomeric transitions with different multipolarities in doubly-odd Tl isotopes.

were established for the first time with half lives of $T_{1/2}$ = 219(12) $\mu$s and $T_{1/2}$ = 3.0(4) ns, respectively. The level scheme of $^{202}$Tl is extended up to $E_X \sim 4MeV$ and $I^\pi = 20^+$, and a total of fifteen new transitions are identified. The reduced $E2$ transition probabilities for the deexcitation of $I^\pi = 2^+$ and $I^\pi = 12^+$ states in Pt isotopes are displayed in Fig. 1. The $B(E2)$ values for the transitions decaying from the $I^\pi = 2^+$ states show a gradual decrease which is expected but an abrupt and unexpected quenching of collectivity around neutron number $N = 120$ is noted for the transition from the $I^\pi = 12^+$ state [1]. Successive multiple nucleon alignments are evident at high spin and the intrinsic contribution to total angular momentum increases significantly at high spins in neutron-rich Pt isotopes [2, 3]. Calculations using the Ultimate Cranker code indicate oblate deformation in all isotopes beyond the first band crossing.

The level schemes for $^{202}$Tl and $^{203}$Pb established from the current work suggest that all levels have predominantly intrinsic character. Excited levels in $^{202}$Tl are fed by the $I^\pi = 20^+$ isomer. Hindrances for several transitions in Tl isotopes are shown in Fig. 2. A large deviation from Weisskopf estimates is seen for $M2$ transitions in contrast to those of other multipolarity. Quasiparticle energies and residual interactions obtained from neighbouring nuclei are used for empirical calculations and shell model calculations using the OXBASH code were also performed. These high-spin results will play a vital role in improving the interactions used in modern-day, large-scale shell model calculations.

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## References

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