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Isomers and oblate rotation in Pt isotopes: Delineating the limit for collectivity at high spins

S.K. Tandel [a,b,*], S.G. Wahid [a], P. Chowdhury [b], R.V.F. Janssens [c], M.P. Carpenter [c], T.L. Khoo [c], F.G. Kondev [c], T. Lauritsen [c], C.J. Lister [b,c], D. Seweryniak [c], S. Zhu [c]

[a] UM-DAE Centre for Excellence in Basic Sciences, Mumbai 400098, India
[b] Department of Physics, University of Massachusetts Lowell, Lowell, MA 01854, USA
[c] Argonne National Laboratory, Argonne, IL 60439, USA

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ABSTRACT

Rotation-aligned isomeric states and associated oblate collective sequences are established in even Pt isotopes. Reduced $E2$ transition probabilities for the deexcitation of the 12^+ isomers indicate an abrupt and unexpected quenching of oblate collectivity around neutron number $N = 120$. Structure and shape evolution at high spin in the heaviest stable isotopes is found to be markedly different from observations in the lighter ones.

The study of shapes and of the interplay between independent-particle and collective degrees of freedom is a major contributor to the successful description of the structure of atomic nuclei. The occupation of specific quantum states by valence protons and neutrons and the nature of the interactions between these are responsible for the realization of deformation and also determine the extent and the nature of collective behavior. Rotation is a dominant collective mode in many quantum systems ranging from molecules to nuclei. Prolate-deformed rotors are known to occur across the entire nuclear chart while, in contrast, collective rotation of oblate-deformed systems is rather uncommon and is particularly disfavored at large angular momenta [1]. This is understood in terms of the higher moments-of-inertia usually associated with prolate states [1] which, in turn, result in the lowering of their excitation energy with respect to that of all other levels. Nevertheless, in the $A \approx 180$–190 region, collective oblate states have been predicted [2] and observed [3–7] at high spin. Here rotation alignment, a process by which pairs of nucleons decouple under the stress of the Coriolis force and align their spin with the rotation axis, favors the occupation of specific orbitals driving the nuclei toward an oblate shape. The present paper provides new insights in this seldom-observed rotational mode by investigating its evolution with angular momentum and isospin while also documenting its competition with the more common prolate rotation.

The lowest states in the rotation-aligned configurations in this region are usually isomeric; *e.g.* the long-lived 12^+ states in even $^{188\text{–}194}$Pt isotopes [5–7]. These 12^+ levels result from the rotation alignment of a pair of $i_{13/2}$ quasineutrons [8]. While there is considerable information on proton-rich, $A \approx 190$ isotopes, the nature of isomerism and the extent of oblate collectivity at high spin on the neutron-rich side of stability is poorly known as this region is difficult to access experimentally. Rotation-aligned isomeric states are not identified in some nuclei, decay paths are not conclusively established in others, and/or data on collective oblate sequences are not available. These factors have severely limited an understanding of the evolution of oblate collectivity. This is in marked contrast with the situation near the ground states, where a gradual decrease in both deformation and collectivity has been well documented for Pt isotopes approaching the $N = 126$ shell closure [9]. In this work, isomer half-lives and $E2$ transition probabilities, along with the magnitude of intrinsic versus collective contributions to the high-spin sequences are determined, providing an understanding of oblate collectivity in the Pt isotopic chain.

* Corresponding author at: UM-DAE Centre for Excellence in Basic Sciences, Mumbai 400098, India.
E-mail address: sujit.tandel@cbs.ac.in (S.K. Tandel).

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Proton-rich Pt isotopes have been studied well through fusion–evaporation reactions [5,6], while there is limited information on the most neutron-rich Pt nuclei populated through fragmentation of a ^{208}Pb projectile [10,11]. The region around ^{196}Pt, which lies between these two extremes, can be best accessed through inelastic excitation or multi-nucleon transfer reactions [7,12]. These techniques can provide detailed spectroscopic information, unlike projectile fragmentation, but are limited to nuclei at or a few nucleons beyond stability.

This Letter reports on the observation of a new 12^+ isomer in ^{196}Pt, on the confirmation of one proposed earlier in ^{198}Pt, and on the firm delineation of the associated decay paths resulting in the inference of reduced $E2$ transition strengths for isomeric decays. An abrupt and hitherto unexpected quenching of oblate collectivity is evident around neutron number $N = 120$. Furthermore, it is found that intrinsic contributions due to nucleon alignments, in comparison to the collective component, play a more important role in angular momentum generation in the rotational bands built on the 12^+ states, with increasing N from ^{192}Pt to ^{196}Pt. The observed progression in the nature of isomerism and oblate collectivity is described both in terms of experimental observables and of results of cranking calculations.

Excited states in Pt isotopes ranging from $A = 188$–198 were populated through $(1p, xn)$ transfer reactions on a ^{197}Au target of ≈50 mg/cm^2 thickness, with a 1450-MeV ^{209}Bi beam from the ATLAS accelerator at Argonne National Laboratory. The Gammasphere detector array [13,14], comprising 100 high-purity, Compton-suppressed Ge detectors was used to record three- and higher-fold γ-ray coincidence events. The data were sorted into a variety of histograms in the following broad categories: (a) two-, three- and four-dimensional symmetric, γ-energy histograms for establishing the excited level structures; (b) energy–energy–time difference histograms for determining isomer half-lives with $T_{1/2} < 10$ ns; (c) time-gated, triple-γ energy coincidence cubes to establish states with $T_{1/2} \gtrsim 10$ ns; (d) prompt-delayed, two- and three-dimensional γ-energy histograms for identifying coincidences across isomeric states; (e) angle-sorted, γ-energy, asymmetric matrices to determine transition multipolarities using the method of directional angular correlations from oriented states (DCO) [15]. Various software packages including RADWARE [16] and TSCAN [17] were utilized for data reduction and analysis.

Rotational sequences in $^{192-196}$Pt are established up to $I \approx 26\ \hbar$, relatively high for this region, with previous information limited to the $I \approx 10$–$20\ \hbar$ range [5,7,12]. The partial decay schemes for the yrast, positive-parity states and relevant negative-parity levels in ^{194,196,198}Pt are displayed in Fig. 1. Representative γ-ray coincidence spectra are presented in Fig. 2. In ^{196}Pt, positive-parity states above 8 $\hbar$ are new in this work, and those above 20 $\hbar$ in ^{192,194}Pt as well. Also, in ^{194}Pt, the relative ordering of the previously identified 183- and 255-keV transitions [7] is changed, and the postulated 12.7-keV, $12^+ \rightarrow 10^+$ transition [8] is included. A new isomer, with $I^\pi = 12^+$ and $T_{1/2} = 7.7(7)$ ns, is established in ^{196}Pt (Fig. 3), and the previously proposed $T_{1/2} = 36(4)$ ns, $I^\pi = 12^+$ state in ^{198}Pt [18] is confirmed (Figs. 1, 3). The excitation energy of the 12^+ state in ^{196}Pt is established through the observation of the 256-keV transition to the negative-parity sequence. DCO ratios of transitions in the yrast, positive-parity structures of ^{192,194,196}Pt indicate their quadrupole character. For example, DCO ratios of 727, 394, 370, 551 and 342-keV transitions in ^{196}Pt (Fig. 1) are 1.14(8), 0.86(5), 0.95(7), 0.85(8), and 0.98(12), respectively. Expected values for quadrupole and dipole transitions are 1.0 and 0.5, respectively. States populated in the decay of the $I^\pi = 12^+$ isomer in ^{198}Pt reported earlier [18] have been verified and firmly established. However, a few of the previous spin-parity assignments [18] are revised; *e.g.*, (a) the 752-keV transition (previously $11^- \rightarrow 8^-$)

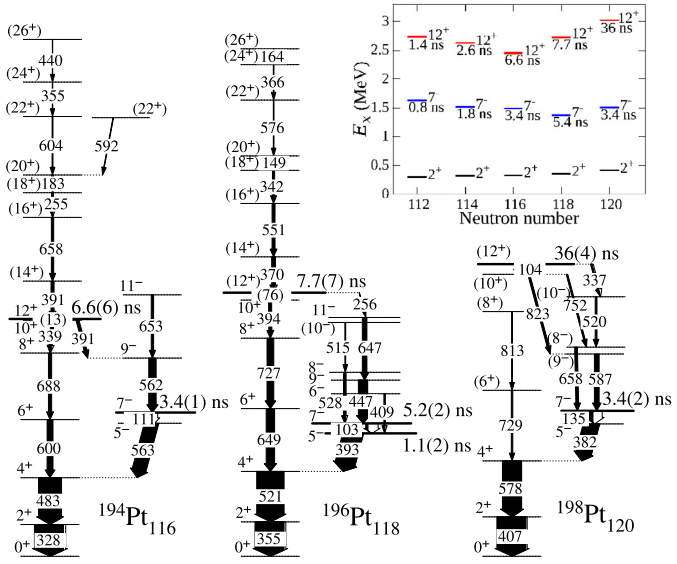

Fig. 1. (Color online.) Partial decay schemes for ^{194,196,198}Pt, displaying the relevant yrast, positive- and negative-parity states. Inset: systematic comparison of excitation energies and half-lives of isomeric states in even-Pt isotopes. Note that the energies of the 2^+ states indicate a gradual decrease in ground-state deformation with neutron number.

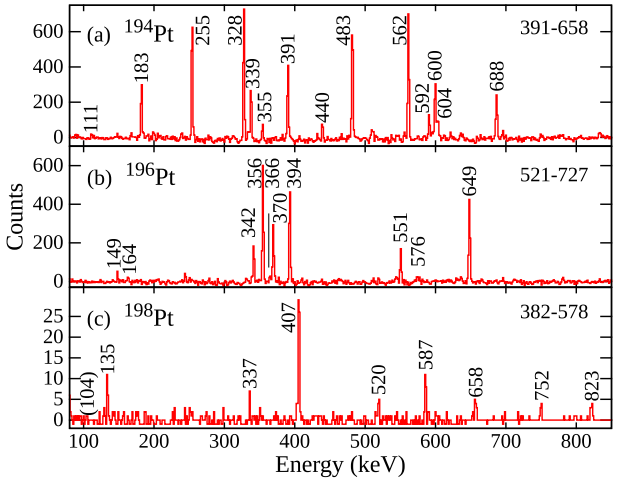

Fig. 2. (Color online.) (a), (b) and (c): Triple-coincidence γ-ray spectra (with gating energies indicated), displaying transitions in the yrast sequences in ^{194,196,198}Pt, respectively. Delayed transitions from the decay of the 12^+ isomer in ^{198}Pt are shown in (c).

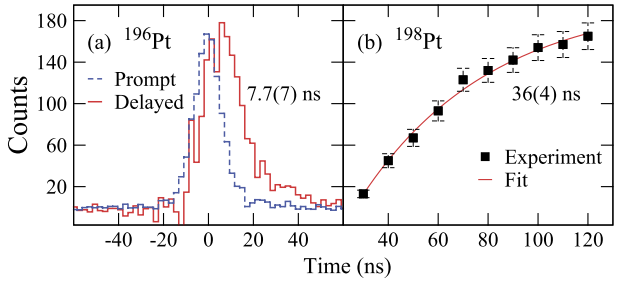

Fig. 3. (Color online.) (a) $T_{1/2} = 7.7(7)$ ns for the 12^+ state in ^{196}Pt determined using the centroid shift method. (b) Time variation in cumulative intensity of delayed transitions from the 12^+ state in ^{198}Pt, from which a half-life of 36(4) ns is inferred.