High-Spin Level Systematics in $^{186-194}$Pt and Rotation-Alignment Coupling*

M. Piiparinen, J. C. Cunnane,† and P. J. Daly
Chemistry Department, Purdue University, West Lafayette, Indiana 47907

and

C. L. Dors, F. M. Bernthal, and T. L. Khoo
Departments of Chemistry and Physics and Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48823
(Received 2 January 1975)

Systematic investigations of the shape-transitional nuclei ^{186}Pt to ^{194}Pt by $(\alpha, xn\gamma)$ reactions have revealed a rich variety of high-spin structural phenomena, which can be qualitatively understood in terms of rotation-alignment coupling and the interplay between collective and single-particle excitation modes. Acute backbending in the positive-parity yrast sequences of ^{188,190,192,194}Pt is attributed to the intersection of rotation-aligned $(\nu i_{13/2}^{-2})$ and $(\pi h_{11/2}^{-2})$ bands with the ground bands.

The level structure of the nuclei $^{186-194}$Pt, which span an important nuclear-shape transition region, has been intensively studied by $(\alpha, xn\gamma)$ spectroscopy. In this Letter we wish to focus attention on several striking systematic aspects of the dominant low-lying high-spin excitation modes in this nuclei, which include (i) well-decoupled $\nu i_{13/2}^{-1}$ bands in all the odd-A nuclei which indicate that the Pt nuclei with $A \geq 187$ are basically oblate; (ii) backbending behavior at about spin 10 in the positive-parity yrast sequences of all the even nuclei, which becomes increasingly more pronounced from ^{186}Pt to ^{192}Pt; (iii) semidecoupled 5^- bands occurring systematically across the even Pt nuclei; (iv) related $\frac{21}{2}^{(-)}$ bands in the odd Pt nuclei, which can be attributed to the coupling of an $i_{13/2}$ neutron hole with the members of the aforementioned 5^- bands.

The experiments were performed by bombarding isotopically enriched ^{192}Os (98%), ^{190}Os (95%), ^{188}Os (87%), and ^{186}Os (62%) targets with 28–50-MeV α-particle beams from the Michigan State University cyclotron. The techniques employed included comprehensive prompt and delayed γ-ray singles and $\gamma\gamma$ coincidence measurements, lifetime measurements, and γ-ray angular-distribution and excitation-function determinations. On the basis of the results, extensive level schemes incorporating a wealth of new spectroscopic information have been constructed. For ^{186,188,190,192}Pt we generally confirm earlier results,[1,2] which were however incomplete and limited to levels with spins ≤ 10. Nothing was previously known about the high-spin level structure of the odd Pt nuclei. Our data for ^{194}Pt are much less extensive than for the other nuclei, since the $(\alpha, 2n)$ reaction only could be studied, and our proposed level scheme is based in part on earlier radioactivity findings.[3,4]

The detailed results for the nine nuclei studied will be presented in forthcoming publications, and the simplified level schemes of Fig. 1 display only the main systematic features of the level spectra. In the odd Pt nuclei, the $\frac{13}{2}^+$ states are low-lying isomers but in Fig. 1 they are displaced to zero excitation energy in order to accentuate the strong correlation between the energy spacings in the $\nu i_{13/2}^{-1}$ decoupled bands and the ground bands of the adjacent core nuclei. Since in this region the low-Ω orbits of the $i_{13/2}$ subshell are close to the Fermi surface only for negative values of β, the observation of these decoupled bands implies oblate deformations for the Pt nuclei with $A \geq 187$.[5] This conclusion must be qualified by a recognition that there is growing evidence for triaxial nuclear shapes in this region.[6]

The energy spacings in the positive-parity yrast sequences of the even-A nuclei are most remarkable, particularly those of ^{190}Pt and ^{192}Pt, which have the appearance of extreme backbending-type structures.[7] For the 192- and 105-keV transitions in ^{190}Pt and ^{192}Pt, we have determined $B(E2; 12^+ \rightarrow 10^+)$ values of about 15 and 39 single particle units (s.p.u.), which are appreciably smaller than the $B(E2; 2^+ \rightarrow 0^+)$ values of 70–80 s.p.u. reported for these nuclei.[8] In an earlier study,[4] the $B(E2)$ for the 339-keV $10^+ \rightarrow 8^+$ transition in ^{194}Pt has been estimated to be about 0.2 s.p.u. In all the even Pt nuclei the 2^+, 4^+, 6^+, and 8^+ levels

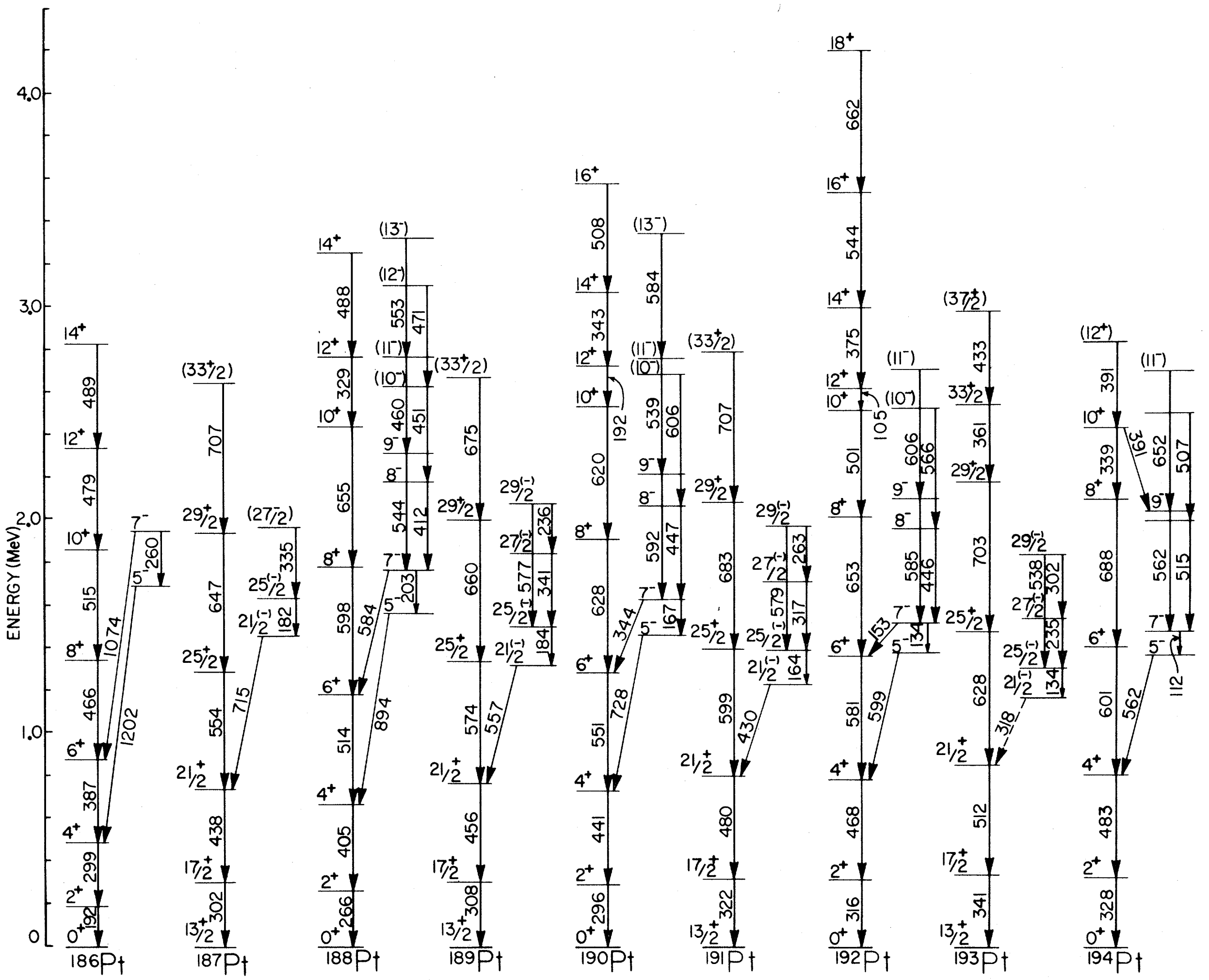

FIG. 1. Level schemes of the nuclei $^{186-194}$Pt. Transition energies are given in keV. The $\frac{13}{2}^+$ states in the odd-A nuclei are low-lying isomers and not the ground states of these nuclei.

are interpreted as ground-band members since their energies are readily fitted with a variable-moment-of-inertia treatment. However, the 10^+ and 12^+ levels in ^{190}Pt, ^{192}Pt, and ^{194}Pt are rather clearly of a different character and the clustering of the levels strongly suggests that they involve the stretch coupling of two high-j particles (holes). In this region, the most probable such configurations are $(\nu i_{13/2}^{-2})$, which gives rise to almost degenerate 10^+ and 12^+ states in light Pb nuclei,[9] and $(\pi h_{11/2}^{-2})$, which is believed to dominate the composition of closely spaced 8^+ and 10^+ states observed at ~ 2.5 MeV in Hg nuclei with $A > 190$.[10]

While a first glance at Fig. 1 might suggest that the $(\nu i_{13/2}^{-2})$ configuration alone is of importance in the Pt nuclei, more detailed consideration of the level systematics leads us to conclude that the $(\pi h_{11/2}^{-2})$ configuration is very probably also involved. Specifically, we propose that the isomeric 10^+ state in ^{194}Pt is predominantly of this two-proton hole character and that the retardation of the 339-keV transition is attributable to the different natures of the 8^+ and 10^+ states. The close resemblance between the energy-level irregularities in the $\nu i_{13/2}^{-1}$ decoupled band of ^{193}Pt and the positive-parity yrast sequence in the ^{194}Pt core nucleus implies the absence of $\nu i_{13/2}$ blocking effects and so one can conclude that the 10^+ state in ^{194}Pt has a dominant intrinsic structure other than $(\nu i_{13/2}^{-2})$; this is almost certainly $(\pi h_{11/2}^{-2})$. Somewhat unexpectedly, the $33/2^+ \to 29/2^+$ reduced $E2$ transition probability in ^{193}Pt was found to be at least twice as great as that of the $10^+ \to 8^+$ transition in ^{194}Pt.

There appears to be every reason to expect the ($\pi h_{11/2}^{-2}$) excitation to occur at about 2.5 MeV in ^{190}Pt and ^{192}Pt as well as in ^{194}Pt since the three isotopes obviously differ only slightly in deformation. Possible 8^+ levels just below the ($\pi h_{11/2}^{-2}$) 10^+ levels would be populated very weakly at best in the yrast cascades because the de-excitation branches to the much lower-lying 8^+ ground-band members are heavily favored by the E_γ^5 dependence of the transition probabilities. In fact, additional 10^+ levels have been located between the 10^+ and 12^+ levels of ^{188}Pt, ^{190}Pt, and ^{192}Pt shown in Fig. 1. Figure 2 displays a particularly interesting portion of the ^{190}Pt level spectrum, in which three 10^+ levels lying within a 168-keV interval have been established. The likely dominant intrinsic configurations appear to be ($\pi h_{11/2}^{-2}$) for the 2536-keV level and ($\nu i_{13/2}^{-2}$) for the close-lying 2702-keV 10^+ and 2727-keV 12^+ levels, while the 2604-keV level occurs near the expected energy of the 10^+ member of the ground band. Similarly, in ^{192}Pt the 12^+ level shown in Fig. 1 and a second 10^+ level observed 41 keV below it may be basically attributed to ($\nu i_{13/2}^{-2}$) and the lowest 10^+ level to ($\pi h_{11/2}^{-2}$). Mixing between the 10^+ and 12^+ levels of the ground bands and the ($\pi h_{11/2}^{-2}$) and the ($\nu i_{13/2}^{-2}$) structures is expected. The mixing can account for the observed enhanced $12^+ \to 10^+$ transition rates in ^{190}Pt and ^{192}Pt and also for the relative intensities of the 123- and 192-keV γ rays in ^{190}Pt (see Fig. 2). This can be shown by a simple three-band calculation, assuming that the $B(E2; 12^+ \to 10^+)$ matrix element within each particular configuration has the full collective strength of a ground-band (g.b.) transition. The agreement with experiment is not significantly affected if the transition within the ($\nu i_{13/2}^{-2}$) structure has only half of the full collective strength, and is also not dependent on a unique set of off-diagonal matrix elements. For example, two satisfactory choices for $\langle \text{g.b.}|H \times|\nu i_{13/2}^{-2}\rangle$, $\langle \text{g.b.}|H|\pi h_{11/2}^{-2}\rangle$, and $\langle \pi h_{11/2}^{-2}|H|\nu i_{13/2}^{-2}\rangle$ are -30, -30, 0 and -20, -20, -20 keV. The structure of the bands built on the 12^+ yrast states in ^{190}Pt and ^{192}Pt provides further support for the proposed dominant ($\nu i_{13/2}^{-2}$) composition of these states. In the framework of the rotation-alignment scheme, the angular momentum of the ($\nu i_{13/2}^{-2}$) $J=12$ configuration should be almost completely aligned by the Coriolis force along the nuclear rotation axis and the energy spacings in the rotation-aligned bands built on these 12^+ states should resemble those of the ground bands of the core nuclei, just as is observed experimentally (Fig. 1).

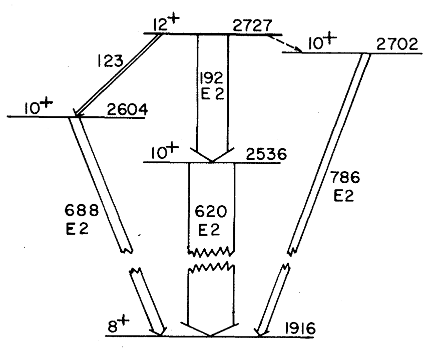

FIG. 2. A detail of the ^{190}Pt level scheme showing the three 10^+ states located.

The less dramatic energy-level irregularities observed in ^{188}Pt are consistent with the foregoing interpretation. Here the lowest 10^+ level is probably now the ground-band member, while the 12^+ level and a 10^+ level located 65 keV below it are tentatively assigned to the ($\nu i_{13/2}^{-2}$) configuration. Effects due to angular-momentum-induced shape transitions might be expected in the transitional Pt nuclei and certain details of the observed level spectra (not shown in Fig. 1) may indeed be attributable to such effects. However, the energy-level irregularities in the positive-parity yrast sequences of the even Pt nuclei ($A = 188-194$) are quite dissimilar to those observed in the ^{184,186,188}Hg ground bands, which exhibit sharp changes from oblate to large prolate deformation at low spin values.[10-12] Our proposal is that the pattern of backbending behavior in this series of Pt nuclei is mainly determined by the intersection of rotation-aligned bands built on the ($\nu i_{13/2}^{-2}$) and ($\pi h_{11/2}^{-2}$) structures with the "normal" ground bands. While the energies of the two-hole structures remain fairly constant, the ground-band moment of inertia decreases with increasing A, so that intersection occurs towards lower spin values as A increases. The overall picture brings to mind vividly the Stephens-Simon explanation[13] of backbending in well-deformed prolate rare-earth nuclei. The specific dominant configurations proposed for the various 10^+ and 12^+ levels are probable rather than certain assignments; subnanosecond-lifetime and g-factor measurements could provide important additional information.

The lower levels in the ^{186}Pt ground band indicate that it is a fairly good rotational nucleus and it may well have prolate deformation.[8,14,15] At present, we report the gentle but definite backbending above the 10^+ ground-band member as an experimental observation, without speculating as to which of several possible effects give rise to it.

Recent model calculations by Vogel and Neergård,[16] incorporating our suggestion that the intrinsic structure of the 5^- bands in this region is dominated by two-quasiparticle components involving a decoupled $i_{13/2}$ neutron and a low-j neutron partner,[2] have successfully reproduced the 5^-, 7^-, 9^-,... level ordering and enhanced $B(E2)$ values observed in even Hg nuclei. Undoubtedly a similar semidecoupled band description applies also to the 5^- bands seen here, and the fact that these bands lie several hundred keV lower in the Pt nuclei than in the corresponding Hg isotopes seems consistent with the occurrence of $(\nu i_{13/2}^{-2})$ excitations at lower energies in Pt than in Hg nuclei. The $\frac{21}{2}^{(-)}$, $\frac{25}{2}^{(-)}$, $\frac{27}{2}^{(-)}$, $\frac{29}{2}^{(-)}$ sequences in the odd Pt nuclei are almost certainly analogous to the bands starting at $\frac{21}{2}^{(-)}$ in odd Hg nuclei, which have been attributed to combinations of $\nu i_{13/2}^{-1}$ with the 5^-, 7^-,... states seen in the neighboring even nuclei.[5,17] The close structural similarities and parallel trends in excitation energy of the 5^- and $\frac{21}{2}^{(-)}$ bands in the Pt nuclei, and, in particular, our determination that the $B(E2)$ values for the $7^- \to 5^-$ and $\frac{25}{2}^{(-)} \to \frac{21}{2}^{(-)}$ transitions in ^{190}Pt–^{194}Pt are all very close to 30 s.p.u., provide fresh and compelling support for the validity of this interpretation.

We thank F. S. Stephens and G. F. Bertsch for stimulating discussions and S. K. Saha for helping in some of the experiments.

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*Research supported by the U.S. Atomic Energy Commission and the National Science Foundation.

†Present address: Schuster Laboratory, University of Manchester, England.

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