LIFETIME MEASUREMENTS IN ^{184}Pt AND THE SHAPE COEXISTENCE PICTURE

U. GARG, A. CHAUDHURY, M.W. DRIGERT, E.G. FUNK, J.W. MIHELICH
Physics Department, University of Notre Dame, Notre Dame, IN 46556, USA

D.C RADFORD[1], H. HELPPI[2], R. HOLZMANN, R.V.F. JANSSENS, T.L. KHOO, A.M. VAN DEN BERG[3]
Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA

and

J.L. WOOD
School of Physics, Georgia Institute of Technology, Atlanta, GA 30332, USA

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Lifetimes for levels in the yrast band of ^{184}Pt have been measured up to spin 16^+ using the recoil distance technique. The $B(E2)$ values exhibit a marked increase in going from spin 2 to 10, consistent with a proposal that two bands of different deformations are mixing at low spin. This provides further support for shape coexistence occurring at low excitation energies in this region.

The structure of the very neutron-deficient Pt ($Z=78$) isotopes is most unusual. Moments of inertia deduced from the excitation energies of the first few excited states show a strong odd–even staggering [1], the odd-mass isotopes showing large deformations ($\hbar^2/2\mathscr{I}\sim 14$ keV). The neighboring Hg ($Z=80$) isotopes show a closely related behavior: a strong odd–even staggering [2] in their isotope shifts, the odd-mass isotopes again showing large deformations ($\beta_2\sim 0.26$). Detailed spectroscopic studies of ^{184,186,188}Hg isotopes (see ref. [3] and references therein) have revealed the coexistence of complete bands of states 0_1^+, 2_1^+, 4_1^+, ...,0_2^+, 2_2^+, 4_2^+, ... corresponding to very different deformations as indicated by energy spacings [3] and $B(E2)$ values [4]. The corresponding even-Pt isotopes do not show such a clear coexistence of bands with different deformation. However, a number of low-lying 0^+ excited states and 2^+ and 4^+ states have been reported [5]. Further, the energy spacings of the yrast band reveal [6] a rapid decrease in the rotational parameter, $\hbar^2/2\mathscr{I}$, from (typically) 27 keV for the $2^+\rightarrow 0^+$ transition to 14 keV for the $8^+\rightarrow 6^+$ transition. It has been argued that these features are indicative of coexisting bands at low energy, albeit masked by band mixing at low spin [6]. The pattern proposed in ref. [6] places the more deformed band lower in energy than the less deformed band.

The structure of the very neutron-deficient Pt isotopes needs to be clarified for a number of reasons: (1) There is an emerging picture of an extensive occurrence of shape coexistence at low energy in the region near $Z=82$ and $N=104$ (see, e.g., refs. [7,8] and the references above). This region needs to be carefully mapped away from closed shells to determine the systematics of band-head energies and mixing matrix elements for the coexisting bands. The present interpretation [6] of the even-mass Os, Pt,

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[1] Present address: Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada K0J 1J0.

[2] Permanent address: Lappeenranta University of Technology, Lappeenranta Finland.

[3] Present address: Rijksuniversiteit Utrecht, Utrecht, The Netherlands.

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Hg and Pb isotopes is very puzzling in that the more deformed band is an excited band in Pb, Hg and Os but is the ground band in Pt (for $A \leqslant 186$). There are a number of detailed calculations of the even-mass Pt isotopes using the interacting boson approximation (IBA). However, descriptions of the neutron-deficient Pt isotopes using IBA [9,10] have not considered the possibility of coexisting bands because of a lack of clear evidence for them. The neighboring even-Hg isotopes are well described [11] by an IBA calculation employing band mixing. The occurrence of coexisting bands in the light even-Pt isotopes is suggested by boson expansion theory calculations [12], fitted potential energy surfaces [13], Hartree–Fock-plus-BCS calculations [14], and calculations [15] using the shell correction method of Strutinsky.

A simple prediction of the interpretation [6] proposed for the very neutron-deficient Pt isotopes is that the B(E2) values in the yrast bands should undergo a rapid increase with increasing spin (matching the decrease in $\hbar^2/2\mathscr{I}$). This increase would reflect the appearance of the full collective strength of the more deformed band, which is masked at low spin due to mixing with the less deformed band. In this letter we report measurements of the lifetimes in the yrast band ^{184}Pt performed using the recoil distance technique [16] to specifically test this prediction. During the course of this work, a similar study of ^{176,178}Pt has been completed by Dracoulis et al. [17]. These authors interpret their data in terms of coexistence of two bands with different deformations.

The high-spin states in ^{184}Pt were populated via the ^{154}Sm(^{34}S, 4n) ^{184}Pt reaction, using 160 MeV ^{34}S ions from the Argonne Tandem–LINAC system. The target was a stretched, thin (0.5 mg cm^{-2}) foil of enriched ^{154}Sm mounted in a recoil distance (plunger) apparatus and was made by evaporation onto a gold foil of ~ 1.3 mg cm^{-2} thickness. Another gold foil (10.2 mg cm^{-2}) was used as the stopper. Gamma rays were detected at 0° with a Ge detector in coincidence with an 8-element large NaI(Tl) sum spectrometer (SS) which surrounded the plunger. Detection of γ-rays from high-spin states was ensured by requiring that at least 2 elements of the SS fire for an event to be acceptable, and appropriate cuts were made in the sum-energy to maximize the yields for the 4n reaction channel. The use of the SS essentially eliminates from the final spectrum all the contaminant γ-rays from radioactivity and Coulomb excitation.

Data were taken at 27 target-to-stopper distances ranging from 4.0 μm to 10 mm giving an effective range of lifetimes between 0.5 ps and several ns. The ratios of intensities of the "unshifted" and "shifted" components of the γ-rays previously known [18] to belong to ^{184}Pt were extracted and fitted for lifetimes using a computer code which incorporates the effects of cascade feeding and corrections due to target thickness, position and velocity dependence of the detector solid angle, detector efficiency, and prompt and delayed side feedings. Fig. 1 presents typical Ge detetor spectra showing "unshifted" and "shifted" peaks for several γ-rays in ^{184}Pt; the relevant portion of the level structure is also shown. It is clear from fig. 1a that the side-feeding components are minimal ($<5\%$) up to the 14^+ level and feedings to these levels have been assumed to be prompt in our analysis. A delayed component ($\tau \sim 2$ ps), evidently from a side band, feeds the 16^+ level and has been taken into account in the extraction of the lifetime for this level. In the absence of reliable data on the $20^+ \rightarrow 18^+$ transition, it is not possible to distinguish the state lifetime from the side-feeding lifetime for the 18^+ level and only a combined lifetime was extracted. The mean lifetimes obtained from the fits to our data are summarized in table 1 which also includes the B(E2) values extracted from the lifetimes. Fig. 2 shows a plot of B(E2)'s versus spin of the depopulating state.

It is clear from fig. 2 that there is a significant increase in the B(E2) values between spins 2^+ and 4^+. This is one of the largest known increases in B(E2) (see below) in going from the 2^+ to 4^+ state and corresponds to an increase in the deformation parameter β from ~ 0.22 to ~ 0.26, if one assumes a deformed rotor interpretation for the band. For an "unmixed" rotational band, β would be constant; the B(E2) values for a constant $\beta = 0.28$ [corresponding to the B(E2) value of the 10^+ state] are also shown in fig. 2 (dashed line). The majority of other nuclei in which a similar (or larger) increase has been observed are those that have been interpreted in terms of shape-coexistence: see, e.g., ^{184,186}Hg [11], ^{176}Pt [17], ^{112}Cd [20], and ^{98,100,102}Mo [21]. Thus the present results are consistent with the behavior

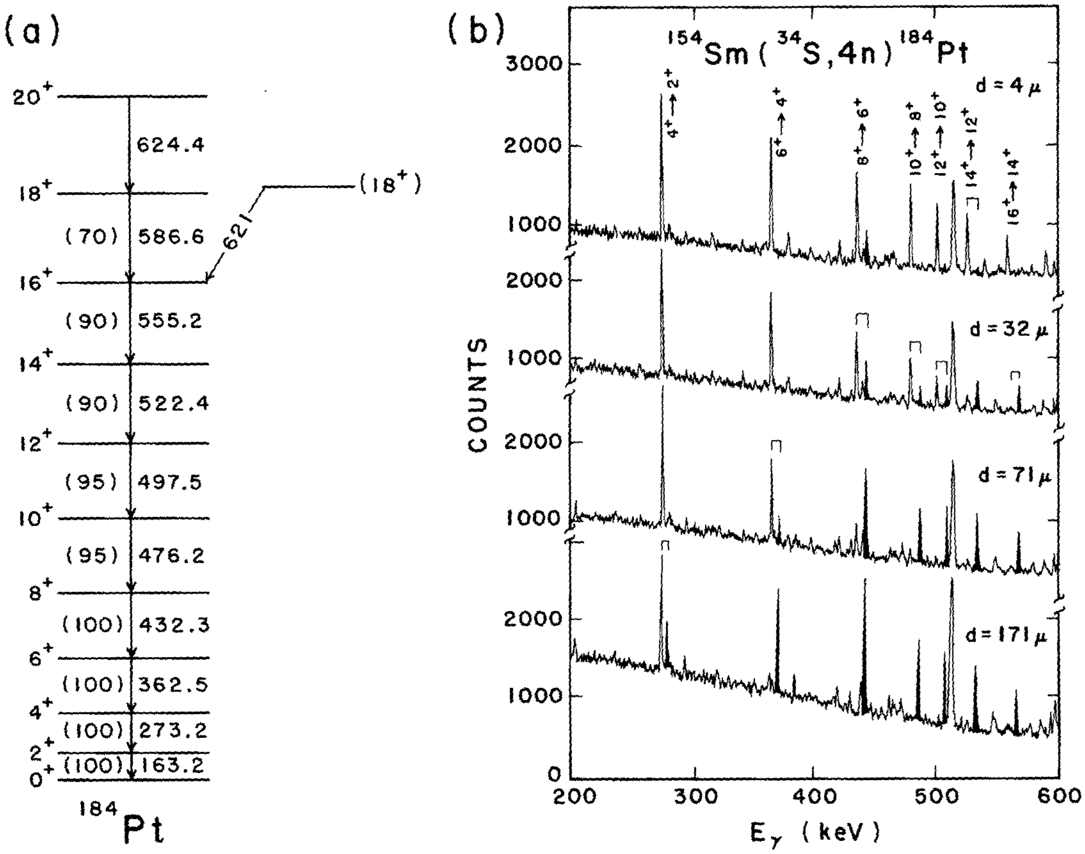

Fig. 1. (a) Relevant level scheme for ^{184}Pt; the numbers in parantheses are relative intensities (±5%). (b) Portions of γ-ray spectra from the ^{154}Sm(^{34}S, 4n) ^{184}Pt reaction at target-to-stopper distances (d) as indicated; the γ-rays known to be from ^{184}Pt are marked and the "shifted" components are shaded.

Table 1

E_γ (keV)	$I_i \to I_f$	Mean lifetime τ (ps)	B(E2)[a]	
			(e^2 fm$^4 \times 10^4$)	(WU)[b]
163	$2^+ \to 0^+$	582 ±22	0.70±0.03	112± 4
272	$4^+ \to 2^+$	36.5±1.3	1.33±0.05	214± 8
363	$6^+ \to 4^+$	8.8±0.4	1.40±0.06	225±10
433	$8^+ \to 6^+$	3.1±0.2	1.68±0.11	270±17
476	$10^+ \to 8^+$	1.7±0.2	1.92±0.23	308±36
497	$12^+ \to 10^+$	2.3±0.2	1.15±0.10	184±16
522	$14^+ \to 12^+$	2.0±0.2	1.03±0.10	166±17
555	$16^+ \to 14^+$	1.7±0.2	0.90±0.11	145±17
586	$18^+ \to 16^+$	2.4±1.4[c]		

[a] Internal conversion ($\alpha_T = \alpha_K + \alpha_L + 1.33\alpha_M$) has been taken into account in calculating B(E2) values. α-values are from ref. [19].

[b] Weisskopf Units. B^W(E2) = 62.2 e^2 fm^4.

[c] It has not been possible to distinguish between the state lifetime and the side-feeding lifetime (see text).

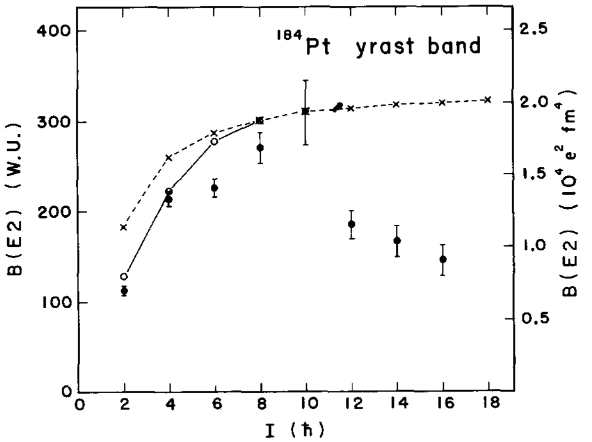

Fig.2. B(E2) values for ^{184}Pt yrast band from the present measurements (solid circles) versus the spin of the depopulating state. The errors shown represent conservative estimates. Also shown are B(E2)'s expected from a rigid rotor model for $\beta = 0.28$ (crosses and dashed lines) and B(E2)'s corresponding to a two-band mixing calculation described in the text (open circles and solid lines); the lines are only to guide the eye.

expected if shape coexistence is present. We also note that there is a large structure change between ^{187}Pt [22] and ^{185}Pt [23] indicating a much larger deformation for ^{185}Pt. This closely parallels the change between ^{187}Hg and ^{185}Hg [2] where shape coexistence is well established. Further evidence for shape coexistence in these nuclei has recently been provided by Dracoulis et al. [17] who, in a two-band mixing analysis of the low-lying states in $^{176-188}$Pt, obtain a smooth variation of band-head energies and mixing matrix elements from their fits to the known energy levels in all these nuclei, thus supporting the reliability of their approach.

A simple band-mixing calculation, similar to one described by Dracoulis et al. for the lighter-mass Pt nuclei [17], has been performed for ^{184}Pt. Assuming that the bands mix only at low spins so that the 6^+ state in the yrast band is fully unmixed, the unperturbed energies of one band (B1) were calculated using a rotational constant of 14.4 keV obtained from the $8^+ \rightarrow 6^+$ transition energy. Taking the first known excited 0+4 state (at 429 keV) [5] as the band-head of the mixing band (B2), the interaction, V, between the unmixed 0^+ states is determined to be $V \simeq 232$ keV. This mixing interaction implies that the ground state of ^{184}Pt is comprised of ~60% B1 (larger deformation) component consistent with the assertion [6] of the more deformed state being lower in excitation energy. Furthermore, the ratio of the calculated B(E2)'s for the $4^+ \rightarrow 2^+$ and $2^+ \rightarrow 0^+$ transitions, respectively, assuming a spin-independent mixing interaction, is 1.75 which compares well with the observed ratio of 1.9. Considering the rather simple nature of these calculations, this agreement is indeed surprising but, nevertheless, tends to support the band-mixing interpretation of the observed behavior. Results of this calculation are also shown (solid line and open circles) in fig. 2.

It should be emphasized that the two-band mixing interpretation of our lifetime data is not unique and other explanations are possible for the observed effect (e.g., centrifugal stretching and variable moments of inertia). In order to better distinguish between the numerous possible "softness" and "band-mixing" interpretations, it would be essential, at the very least, to obtain lifetimes of other states, for example, the excited 0^+ and 2_2^+ states; these lifetimes are not known at present. Further, to our knowledge, there are no detailed calculations yet available for ^{184}Pt in the framework of any of the models that would account for the observed behavior.

A separate and intriguing aspect of our measurements is the decline in B(E2) values beyond spin 10^+. This might be indicative of the onset of triaxiality. It occurs in the region of backbending in the yrast band and is possibly the result of a large induced triaxiality due to the addition of a pair of $i_{13/2}$ quasineutrons. Such behavior has recently been observed in the deformed rare-earth nuclei [24]. A possible emergence of triaxiality has been reported in ^{186}Hg as well [25].

The present results are consistent with shape coexistence in ^{184}Pt. This should encourage a theoretical treatment of the very neutron-deficient even-Pt isotopes using the IBA band-mixing formalism, such as in the case of the neighboring Hg isotopes [11]. According to the systematics [1,6] of yrast bands in the neighboring Pt isotopes, a similar behavior of B(E2)'s in the yrast band should be seen in other Pt nuclei with $A \leqslant 186$ and recent results in ^{176,178}Pt [17] are consistent with this expectation. A study of the rest of these isotopes would further test the premise of shape coexistence in the light-mass Pt nuclei.

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