Levels in ^{184}Pt, ^{186}Pt, and ^{188}Pt†

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The nuclear decay chains beginning with the neutron-deficient isotopes ^{184}Hg, ^{186}Hg, and ^{188}Hg have been studied using isotopically separated sources from the Princeton on-line isotope-separator facility. Ge(Li) and Si(Li) singles spectra and Ge(Li)-Ge(Li) coincidence spectra have been obtained and used in constructing level schemes for the corresponding platinum daughters. Systematics of experimental energy levels and ratios $B(E2, 2' \rightarrow 2)/B(E2, 2' \rightarrow 0)$ for all known even platinum isotopes are given.

I. INTRODUCTION

The platinum isotopes occupy the transition region between the spherical nuclei centered about lead and the nuclei with large deformation centered in the rare-earth region. The level structure of the even-even platinum isotopes exhibits a slow transition from a vibrational pattern at the high-mass end to a rotation-like behavior at the low-mass end. The study of these nuclides is therefore of considerable interest in attempting to understand the structure of the collective states observed.

Although the phenomenological vibrational and rotational descriptions of spherical and deformed nuclei have enjoyed some success in the understanding of collective excitations, they have proved to be somewhat inadequate in predictions of detailed properties of some of these levels. In addition, these two models are limited in their range of applicability.

Two, more recently proposed models attempt to provide a wider applicability. The phenomenological variable-moment-of-inertia (VMI) model of Mariscotti, Scharff-Goldhaber, and Buck[1] attempts a systematization of the energy levels of ground-state rotational and quasirotational bands observed in even-even nuclei. This model appears inapplicable only to the few nuclides which are more or less satisfactorily described by the vibrational model.

Baranger and Kumar[2] have performed quite extensive calculations using a microscopic pairing-plus-quadrupole residual interaction between shell-model states. This pairing-plus-quadrupole (PPQ) model[2] reproduces the energy spectrum very well. It predicts magnetic dipole and electric quadrupole moments as well as reduced transition probabilities. The application of the PPQ model to W, Os, and Pt nuclei has been particularly successful.

The study of the structure of the neutron-deficient even-even platinum nuclei was the first project undertaken with the POLARIS facility,[3] an isotope separator on-line at the Princeton-Pennsylvania accelerator. This choice was made as much on technological grounds as on the basis of the scientific interest mentioned above. The relative ease in obtaining radioactive sources of neutron-deficient Hg isotopes from molten-lead on-line targets made this choice a natural one for the initial experiments performed with POLARIS. Some preliminary results on these nuclei were available from the ISOLDE group,[4] which has performed similar experiments. In addition to the ISOLDE data, some results of other investigations of neutron-deficient even platinum isotopes have also been reported.[5-9]

The present paper presents the results of the Princeton studies performed on the level structure of ^{184,186,188}Pt revealed by the electron capture and β^+ decays of the corresponding gold nuclides.

II. EXPERIMENTAL PROCEDURE

Neutron-deficient isotopes of mercury were produced by bombarding a molten-lead target with 3-GeV protons in the external beam of the Princeton-Pennsylvania accelerator. Chemical and mass separations were performed by means of the POLARIS on-line isotope-separator facility which is described elsewhere.[3]

The decay chains beginning with the mercury isotopes were observed by means of Ge(Li) and Si(Li) singles spectrometers and a Ge(Li)-Ge(Li) coincidence spectrometer. In addition to measurements obtained with the complete POLARIS facility, spectra of the longer-lived isotopes were also acquired by means of off-line data taking. Here the separated isotopes were collected on a foil placed at the focal plane of the isotope separator. After a collection time typically equal to two or three half-lives of the gold isotope of interest, the collection foil was removed and sectioned, the appropriate strip then being used as a spectroscopy source.

Data were taken using the first sample while the isotope separator was being prepared and a second sample was being collected. The second sample then replaced the first as the spectroscopy source while a third sample was obtained. This process continued until sufficient statistical accuracy of the data had been obtained.

The assignment of γ-ray and conversion-electron lines to a particular isobar in a given mass chain was accomplished by comparing the relative intensities of the lines in successively obtained spectra, and/or by obtaining spectra of the separated gold fraction. The latter samples were obtained by collecting the mass-separated beam on a platinum foil and then flaming it, thereby driving off the mercury atoms.

The γ-ray singles measurements were made with a Ge(Li) detector having an active volume of 15 cm^3 and a system resolution at the 1.33-MeV line of ^{60}Co of approximately 3-keV full width at half maximum (FWHM). Conversion-electron spectra were taken with a Si(Li) detector having an area of 80 mm^2 and a 3-mm depletion depth. With this detector, the system resolution was approximately 6-keV FWHM at the K conversion line of the 661-keV transition in ^{137}Cs. From the measured conversion-electron and γ-ray relative intensities, the internal-conversion coefficients could be calculated by the comparison method, provided that the multipolarity of one transition was known. This was always taken to be the pure $E2$ transition from the first excited 2+ level to the 0+ ground state in the even-even platinum isotopes.

Because of the complexity of the γ-ray spectra, it was necessary to use two Ge(Li) detectors for the coincidence experiments. The detector mentioned above was used to obtain the coincidence spectrum, while the energy gates were set on the spectrum obtained with a detector having an active volume of 30 cm^3 and a resolution of about 5 keV.

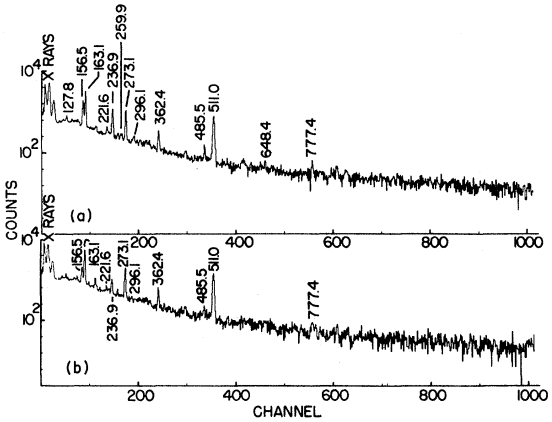

FIG. 1. Consecutive γ-ray spectra of the $A=184$ decay chain. (Energies in keV.)

III. RESULTS AND CONCLUSIONS

A. $A = 184$

The short half-lives[9] of the ^{184}Hg (33 sec) and ^{184}Au (52 sec) required that all measurements be performed using the moving-tape collection apparatus of the complete on-line system. Employing 3-min collection and counting periods, a number of Ge(Li) singles spectra of the mass-184 decay chain were obtained; two sets of 3-min spectra and three sets of 3×1-min consecutive spectra.

Two of the consecutive spectra taken immediately after collection are shown in Fig. 1. These indicate the relative ease with which it is possible to distinguish the γ-ray lines arising from the decay of the different isobars in the chain. The energies and intensities of the transitions which have been assigned as following the decay of ^{184}Hg and ^{184}Au are listed in Table I.

One coincidence experiment was carried out which enabled us to place the stronger transitions assigned to the ^{184}Au decay in a partial level scheme for ^{184}Pt. Comparison of the spectra obtained with energy gates set on the 163.1-keV photopeak and on the Compton background above it indicates that it is in coincidence with the transitions of energies 273.1 and 362.4 keV, and probably in coincidence with the 485.5-keV transition.

The partial level scheme proposed for ^{184}Pt is shown in Fig. 2. It is based primarily upon the coincidence data. The level at 648.5 keV is placed because of γ-ray energy sums and the probable 163.1-485.5-keV coincidence. The level at 940.5

TABLE I. Energies and relative intensities for γ transitions following the decays of ^{184}Hg and ^{184}Au.

Decay of	E (keV)	I_γ (relative)
^{184}Hg	127.8 ± 0.6	6.6 ± 3.5
	156.5 ± 0.6	65 ± 7
	236.9 ± 0.7	100 ± 10 [a]
	259.9 ± 0.8	11 ± 6
	262.9 ± 0.8	6.3 ± 3.5
	296.1 ± 0.9	14 ± 7
^{184}Au	163.1 ± 0.6	100 ± 10 [a]
	221.6 ± 0.7	7.4 ± 2.5
	273.1 ± 0.8	84 ± 11
	362.4 ± 1.2	40 ± 6
	485.5 ± 1.7	14 ± 5
	648.4 ± 2.4	7.1 ± 3.0
	777.4 ± 3.9	18 ± 10

[a] Normalization.

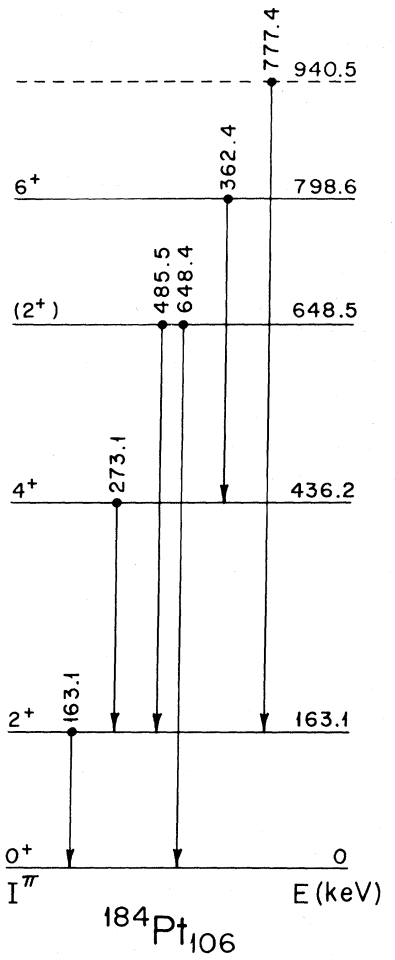

FIG. 2. Partial energy-level scheme for ^{184}Pt.

keV is tentative and, therefore, shown by a dashed line.

Because no conversion-electron spectra could be obtained for the $A = 184$ decay chain, no multipolarities were determined; the spin-parity assignments are tentative. The 163.1-, 436.2-, and 798.6-keV levels have been interpreted as the 2^+, 4^+, and 6^+ members of the quasirotational ground-state band. This assignment is in agreement with the (HI, $xn\gamma$) results of Burde, Diamond, and Stephens (BDS)[6] who observed members of this band up to $I = 16$, and with those of the ISOLDE group.[4] The tentative assignment of $I^\pi = 2^+$ to the 648.5-keV level is based upon the γ-ray branching intensity and the systematics observed in the other even-even platinum isotopes.

B. $A = 186$

Studies of the decay of ^{186}Hg require the use of the complete on-line system because of the 1.4-min half-life[10] of this nuclide. The relatively long,

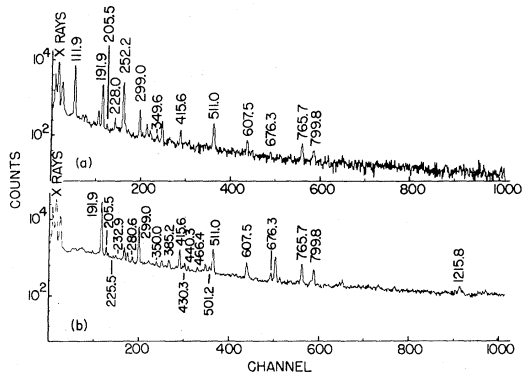

FIG. 3. (a) γ-ray spectrum of the $A = 186$ decay chain, (b) the same after driving off the Hg fraction. (Energies in keV.)

11-min, half-life[8,11] of ^{186}Au, however, permits the use of off-line detection equipment. Consequently, Ge(Li) γ-ray singles spectra were obtained with both experimental arrangements. The on-line system was used to obtain a 12-min spectrum and a set of 3×1-min consecutive spectra. With the off-line detector one set each of 4×2 and 4×12-min consecutive spectra were obtained, as well as one spectrum taken 2 h after sample collection.

TABLE II. Energies and relative intensities for γ transitions following the decays of ^{186}Hg and ^{186}Au.

Decay of	E (keV)	I_γ (relative)
^{186}Hg	111.9 ± 0.4	100 ± 12 [a]
	228.0 ± 0.4	3.3 ± 1.0
	252.2 ± 0.4	100 ± 15
	349.6 ± 0.5	3.2 ± 1.6
^{186}Au	191.9 ± 0.4	100 ± 10 [a]
	205.5 ± 0.4	2.8 ± 0.8
	225.5 ± 0.4	0.6 ± 0.3
	232.9 ± 0.4	0.8 ± 0.4
	280.6 ± 0.4 [b]	1.0 ± 0.6
	299.0 ± 0.4	42 ± 5
	350.0 ± 0.5	1.7 ± 0.9
	385.2 ± 0.6	5.0 ± 1.8
	388.0 ± 0.6	1.8 ± 1.6
	415.6 ± 0.6	13 ± 2
	430.3 ± 0.6	3.5 ± 1.5
	440.3 ± 0.6	2.1 ± 1.0
	466.4 ± 0.6	2.0 ± 1.0
	501.2 ± 0.7	4.4 ± 1.5
	607.5 ± 0.7	12 ± 2
	676.3 ± 1.0	3.7 ± 1.9
	765.7 ± 1.3	14 ± 3
	799.8 ± 1.3	9.7 ± 2.5
	1215.8 ± 2.7	2 ± 1

[a] Normalization.
[b] Assignment to ^{186}Pt not certain.

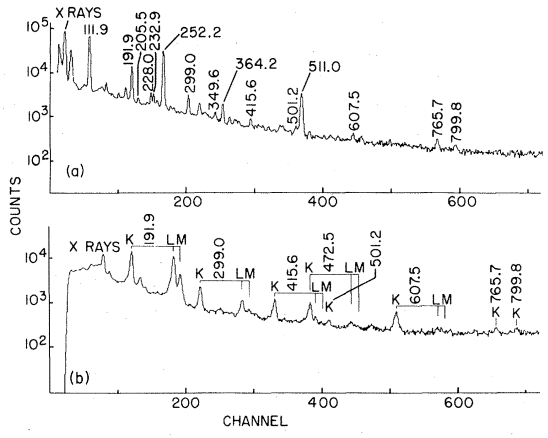

FIG. 4. (a) γ-ray spectrum of the $A=186$ decay chain; (b) conversion-electron spectrum of the $A=186$ chain. (Energies in keV.)

One further set of γ-ray spectra were taken with the off-line detector. Immediately after collection, on a platinum foil, a 12-min spectrum, Fig. 3(a), was taken for the $A=186$ sample. The Hg fraction was then driven off by bringing the platinum foil to red heat, and a set of 3×16-min spectra was obtained, the first of which is shown in Fig. 3(b). The results of these measurements, in particular, served to establish the assignment of the γ-ray transitions to the decays of ^{186}Hg and ^{186}Au. The energies and relative intensities for these isobars are listed in Table II.

Two sets of 4×12-min consecutive conversion-electron spectra were obtained with an off-line Si(Li) spectrometer. One of these is shown in Fig. 4, where it is compared with the γ-ray singles spectrum obtained on line. The energies, internal-conversion coefficients, and multipolarity assignments of some transitions which have been assigned to ^{186}Pt are listed in Table III.

The electron lines at energies 394.1 and 458.8 keV are interpreted as K and L lines, respectively, of a 472.5-keV transition converted in ^{186}Pt. Since no γ transition of this energy could be observed in the decay of ^{186}Au, only lower limits can be given for the K and L conversion coefficients. From these we have to assign $E0$ multipolarity to the 472-keV transition. A transition of 471.5 keV with a conversion coefficient $\alpha_K>0.22$ has been tentatively assigned on the basis of its half-life to the decay of ^{188}Au by Johansson *et al.*[8] Since we find no evidence for a transition of this energy in our mass-separated samples of $A=188$ (see Sec. III C) and these authors used unseparated samples, we suggest that the 472-keV transition rather be assigned to the ^{186}Au decay. However, we cannot rule out with absolute certainty a cross contamination from $A=187$ in our mass-separated $A=186$ sample. The high conversion coefficient and the multipolarity of the 608-keV transition(s) are discussed below.

Several Ge(Li)-Ge(Li) coincidence experiments were performed in order to find the ^{186}Pt energy level scheme. In each case, two spectra were recorded simultaneously. One spectrum was obtained with the energy gate set on a photopeak, the other with the gate set on the Compton background

TABLE III. Conversion-electron lines and conversion coefficients for some transitions in ^{186}Pt.

Transition energy (keV)	E_{e^-} (keV)	Shell	I_{e^-} (relative)	α	Multipolarity
191.9	113.0 ± 0.6	K	19.5	0.195 [a]	$E2$
	179.2 ± 0.6	L	16.9	0.169	
	189.8 ± 0.6	M	4.5	0.045	
299.0	221.0 ± 0.6	K	3.0	0.071	$E2$
	287.0 ± 0.7	L	1.3	0.030	
	297.9 ± 0.7	M	0.2	0.004	
415.6	338.5 ± 0.7	K	1.4	0.104	$M1/E2$
	402.8 ± 0.7	L	0.16	0.012	
472.5 [b]	394.1 ± 0.7	K	1.3	>20	$E0$
	458.8 ± 0.7	L	0.18	>2.8	
501.2	424.2 ± 0.7	K	0.22	0.05	$M1/E2$
	491.5 ± 0.8	L	0.15	0.03	
607.5	529.5 ± 0.8	K	0.96	0.08	(see text)
765.7	688.1 ± 0.8	K	0.13	0.009	$E2/M1$
799.8	722 ± 1	K	0.09	0.009	$E2/M1$

[a] Normalization.

[b] No γ line of this energy observed in ^{186}Pt.

above this photopeak. The results of these coincidence experiments are summarized in Table IV.

The above experimental data suggest the ^{186}Pt level scheme shown in Fig. 5. The levels at 191.9, 490.9, and 878.9 keV have been interpreted as the 2^+, 4^+, and 6^+ members of the ground-state band, which is in agreement with the results of BDS[6] and those of Foucher *et al.*[4] The 2^+ level at 607.5 keV is also proposed by the ISOLDE group,[4] and thus, appears to be well established.

There are at least two possibilities for placing the 472.5-keV $E0$ transition which we have tentatively assigned to ^{186}Pt. One is to assign it as a transition between a 0^+ level at 472.5 keV and the 0^+ ground state. This interpretation would be supported by the energy sum of the 191.9- and the 280.6-keV transitions, which would represent a depopulation of the proposed 0^+ excited level via a cascade with the first excited state at 191.9 keV as intermediate. The assignment of the 280.6-keV transition to ^{186}Pt, however, is also uncertain. Furthermore, the energy-level systematics of the heavier even-even Pt nuclides as well as the theoretical calculations of Kumar[12] would not lead us to expect a 0^+ level at this low excitation energy.

An investigation of the conversion-electron spectrum up to an energy of 1 MeV shows no strong $E0$ transition corresponding to the deexcitation of a higher-lying 0^+ level which could be fed by the 472.5-keV transition. However, the experimental K conversion coefficient of the 607.5-keV transition [$\alpha_K(608, \text{exp}) = 0.08 \pm 0.02$, Table III] is much too high to be compatible with the assumed $E2$ multipolarity of this transition [$\alpha_K(608, E2) = 0.012$]. This leads us to conclude that either the 607.5-keV transition is of higher multipole order or that the 529.5-keV conversion-electron line is a doublet composed of the K electrons of a 607.5-keV $E2$ transition and an unresolved $E0$ transition. The former possibility is contradicted by the $M1/E2$ multipolarity of the 415.6-keV stopover transition, leaving the latter possibility. Thus, the first excited 0^+ state would have an energy of approximately 608 keV. This state could be fed from a second excited 0^+ level at about 1080 keV via the 472-keV $E0$ transition. This interpretation appears to be the most consistent, and is the one tentatively shown by dashed lines in the level scheme. It would be helpful, however, to obtain electron-electron and γ-electron coincidence measurements in order to check this interpretation.

Recently, we have been informed[13] that there is evidence for a γ-ray doublet at 608 keV in the tran-

TABLE IV. Results of coincidence measurements in ^{186}Pt.

E (keV)	191.9	299.0	415.6
191.9		a	a
205.5	a		a
280.6	b		
299.0	a		
350.0	a		
385.2			a
388.0	a		
415.6	a		
430.3	a		
501.2	a	a	
511.0	a	a	a
765.7	a		

[a] Coincidence.
[b] Possible coincidence.

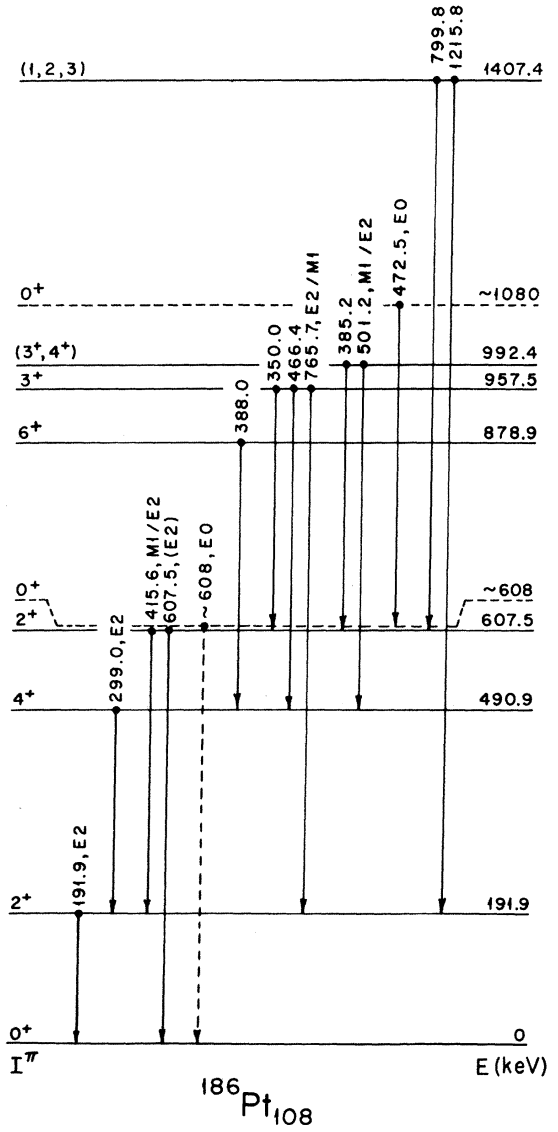

FIG. 5. Partial energy-level scheme for ^{186}Pt.

sitions accompanying the decay of ^{186}Au. This observation would be incompatible with our suggestion of a 0^+ level at ~608 keV. The high conversion coefficient we report here is confirmed, however, which would require an unusually large $E0$ admixture in the transition.

We have assigned $I^\pi = 3^+$ to the 957.5-keV state because this is consistent with the $E2/M1$ multipolarity of the 765.7-keV transition and with the branching of the γ rays deexciting this level.

The K conversion coefficient of the 501.2-keV transition is consistent with an $M1/E2$ mixing. Since it feeds a 4^+ level, spins 3, 4, or 5 and positive parity can be expected for the 992.4-keV state. Spin 5 appears to be ruled out by the fact that the 385.2-keV transition, which also depopulates this level, feeds a 2^+ state.

The 1407.4-keV level is proposed on the basis of energy sums. Although the same considerations would allow the placement of the 799.8-keV transition between the 992.4- and the 191.9-keV states, it does not appear in the spectrum coincident with the 191.9-keV transition. The possible spins of 1, 2, or 3 for the 1407.4-keV level are based upon the internal-conversion coefficient of the 799.8-keV transition.

C. $A = 188$

The longer half-lives[11] of ^{188}Hg (3.7 min) and ^{188}Au (8 min) permitted the use of off-line detectors. Only one 4-min spectrum was taken with the complete on-line system. One set of four consecutive Ge(Li) γ-ray spectra, 4 min each, was obtained with the off-line system. Also a series of measurements with separation by flaming was performed. The latter consisted of a 3-min spectrum, shown in Fig. 6(a), of the isobarically mixed sample taken immediately after isotopic separation, followed by a set of 3×8-min consecutive spectra taken after the Hg had been driven off. The first of these is shown in Fig. 6(b). These measurements led to the assignment of γ-ray transitions to the decays of ^{188}Hg and ^{188}Au. The energies and relative intensities of these transitions are listed in Table V.

TABLE V. Energies and relative intensities for γ transitions following the decay of ^{188}Hg and ^{188}Au.

Decay of	E (keV)	I_γ (relative)
^{188}Hg	114.5 ± 0.5	51 ± 8
	135.3 ± 0.5	18 ± 17
	155.7 ± 0.5	29 ± 9
	190.7 ± 0.5	100 ± 10 [a]
	204.3 ± 0.5	24 ± 8
	253.3 ± 0.5	61 ± 29
	523.8 ± 0.7	20 ± 12
^{188}Au	266.0 ± 0.4	100 ± 10 [a]
	330.7 ± 0.5	7.9 ± 1.2
	340.1 ± 0.5	22.7 ± 3.0
	405.5 ± 0.5	7.7 ± 2.0
	412.7 ± 0.5	2.0 ± 1.5
	533.4 ± 0.6	4.1 ± 2.0
	606.0 ± 0.7	15.5 ± 2.1
	670.7 ± 0.8	5.2 ± 2.1
	678.0 ± 0.8	2.5 ± 1.2
	1083 ± 2	4.0 ± 2.5
	1114 ± 3	2.5 ± 1.5

[a] Normalization.

Four consecutive conversion-electron spectra were taken for a period of 8 min each with an off-line Si(Li) spectrometer. The first of these is shown in Fig. 7 in which it is compared with a 4-min Ge(Li) γ-ray spectrum. The energies, relative intensities, and internal-conversion coefficients of the conversion-electron lines assigned to ^{188}Pt are listed in Table VI.

Coincidence experiments, as described above in the case of ^{186}Pt, were also performed for the

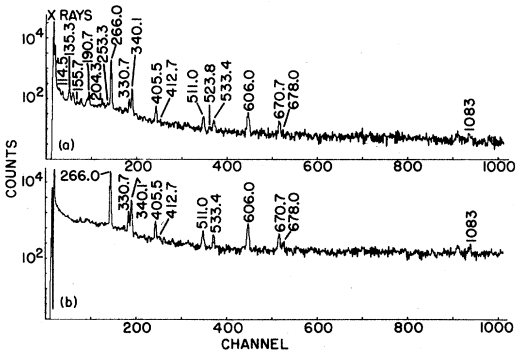

FIG. 6. (a) γ-ray spectrum of the $A = 188$ decay chain, (b) the same after driving off the Hg fraction. (Energies in keV.)

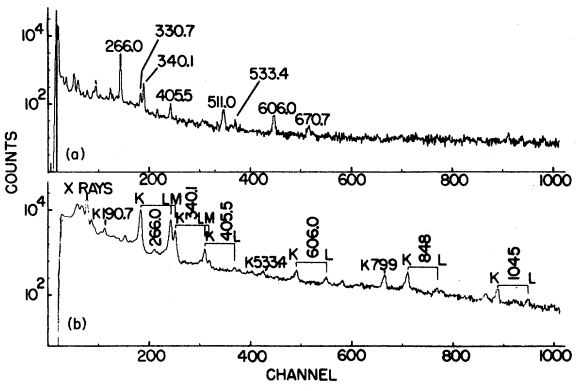

FIG. 7. (a) γ-ray spectrum of the $A = 188$ decay chain; (b) conversion-electron spectrum of the $A = 188$ chain. (Energies in keV.)

TABLE VI. Conversion-electron lines and conversion coefficients for some transitions in ^{188}Pt.

Transition energy (keV)	E_{e^-} (keV)	Shell	I_{e^-} (relative)	α	Multipolarity
266.0	187.9 ± 0.6	K	7.50	0.075 [a]	$E2$
	253.8 ± 0.6	L	3.18	0.032	
340.1	263.7 ± 0.6	K	1.25	0.055	$E2/M1$
	338.8 ± 0.6	M	0.09	0.004	
533.4	457.3 ± 0.4	K	0.059	0.014	$E2$
606.0	529.0 ± 0.8	K	0.131	0.009	$E2$
799.4 [b]	722.2 ± 0.8	K	0.182	>2	$E0$
848 [b]	772.5 ± 0.9	K	0.319	>3	$E0$
1045 [b]	968.7 ± 1.2	K	0.059	>1	$E0$

[a] Normalization.

[b] No γ line of this energy observed.

^{188}Pt γ-ray transitions and the results of these are summarized in Table VII.

The ^{188}Pt level scheme constructed on the basis of the above results is shown in Fig. 8. It is in agreement with earlier results[4-7] up to an excitation energy of 1.4 MeV, except that we tentatively assign a spin of 3 or 4 to the 1349.5-keV level, based on the γ-ray branching. The two strong conversion-electron lines at 772.5 and 968.7 keV are apparently conversions in the K shell of $E0$ transitions depopulating 0^+ states. The placement of these two levels cannot be determined from our data, but it does appear likely that both are at excitation energies greater than 1 MeV. We therefore tentatively place two additional 0^+ states at 1647 and 1844 keV.

IV. DISCUSSION

Spin and parity assignments for the lower excited states in the even-even isotopes $^{182-198}$Pt are well established from the work of several groups[4-8, 11, 14, 15-20] and this investigation. In particular, the in-beam spectroscopic studies have served to establish a sequence of states in the quasirotational ground-state bands in these nuclides. In Fig. 9 the energy ratio E_I/IE_2 for these states is plotted versus the spin I. This illustrates the transitional character of these nuclides, the values lying about half way between the rotational and vibrational limits with a trend towards rotationlike behavior for the lighter isotopes.

TABLE VII. Results of coincidence measurements in ^{188}Pt.

E (keV)	266.0	330.7	340.1	405.5
266.0		a	a	a
330.7			a	
340.1	a	a		
405.5	a			
533.4	a			
606.0		a		
670.7	a			

[a] Coincidence.

The known levels in the ground-state band for all of these isotopes have been fitted[1] with the two-parameter VMI model, and show remarkable agreement. In almost every case, the fitted energy value is within 2% of the experimentally determined value and in most cases, it is within 1%. This model, however, is not capable of predicting the positions of levels not in the ground-state band. Baranger and Kumar[2] have calculated the energy spectra to be expected on the basis of their QPP model for $^{192-196}$Pt. The results are in relatively good (within 5%) agreement with the experimental energies for the two members of the ground-state band considered, but are rather less accurate in reproducing the $2^{+\prime}$, 0^+, and 3^+ states. A more recent calculation by Kumar[12] for ^{186}Pt, however, is in excellent (within 2%) agreement with the experimental values except for the tentative 0^+ excited state. Furthermore, both sets of calculations do predict more or less correctly the systematic trend in the behavior of the levels from isotope to isotope. In particular, the crossing of the 4^+ and 2^+ levels at ^{186}Pt is correctly predicted.

The systematics of the known energy levels in the even-even Pt isotopes are shown in Fig. 10. The regularity in the corresponding levels in the different isotopes is striking, as is the apparent difference in character between the members of the ground-state band and the $2^{+\prime}$ and 3^+ levels as indicated by this figure.

The 3^+ states for ^{188}Pt and the heavier isotopes are located above the $2^{+\prime}$ state by an energy interval approximately equal to the energy of the first excited 2^+ level, as properly predicted by the rigid-asymmetric-rotor model of Davydov and Filippov.[21]

The indications of low-lying excited 0^+ states appears of interest. Such states could be pictured as arising from either a second minimum in the nuclear potential-energy surface or from a collective vibration (e.g., β vibration).

Kumar and Baranger[2] have suggested that the wave functions of the platinum isotopes are spread over the entire β-γ plane and that excited 0^+ states for platinum 192, 194, and 196 lie above 1 MeV. Recently Kumar has predicted the $0^{+\prime}$ in platinum 186 to occur at 794 keV in fair agreement with the trend observed experimentally.[12]

In zero order a 0^+ state would be expected for

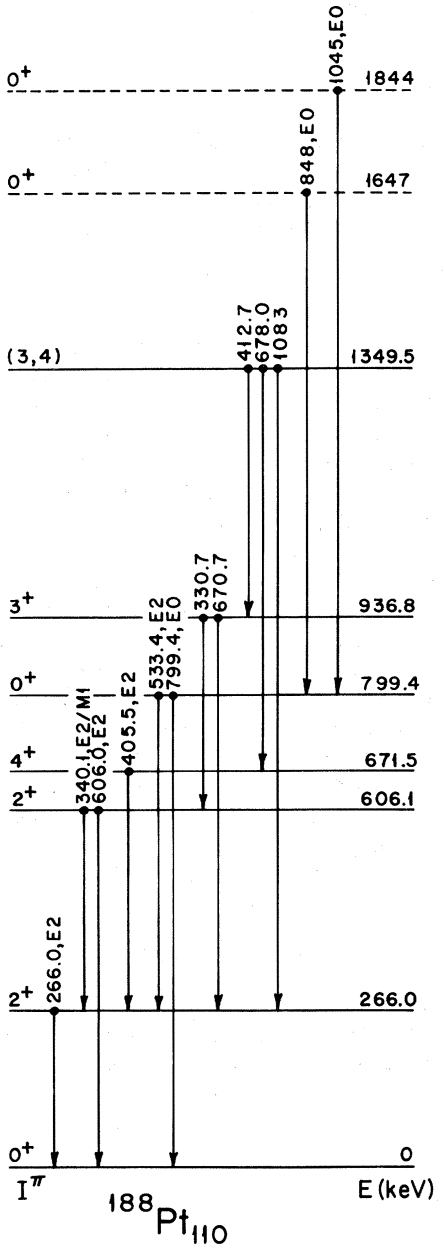

FIG. 8. Partial energy-level scheme for ^{188}Pt.

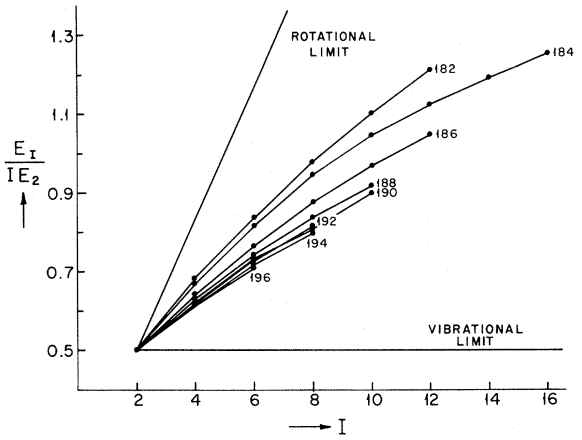

FIG. 9. Energy ratios for the ground-state band levels in even-even Pt isotopes. The values for the energies were taken from Refs. 4–7, 11, and from our measurements.

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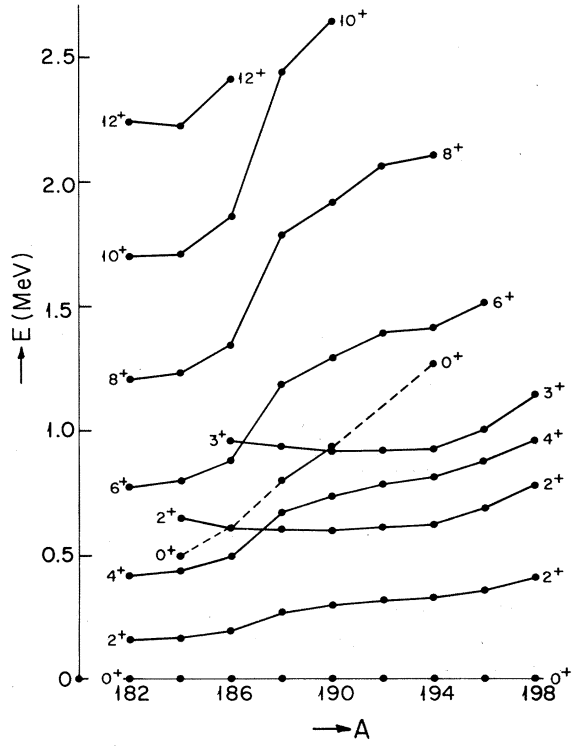

FIG. 10 Systematics of the low-lying excited levels in even-even Pt isotopes. The values for the energies were taken from Refs. 4–7, 11, and from our measurements.

TABLE VIII. $B(E2)$ ratios $R = B(E2, 2^{+\prime} \rightarrow 2^{+})/B(E2, 2^{+\prime} \rightarrow 0^{+})$ for even-even Pt isotopes.

Nucleus	R (exp.)	$E(2^{+\prime})/E(2^{+})$	γ (deg)	R (theor.) [a]	R (theor.) [b]
^{184}Pt	1.0 ± 0.5 [c]	3.98	19.5	5.0	...
^{186}Pt	1.0 ± 0.4 [c]	3.17	21.7	7.6	...
^{188}Pt	2.7 ± 0.7 [c]	2.28	26	31.2	...
^{190}Pt	50 ± 8 [d]	2.02	29	363	...
^{192}Pt	186 ± 24 [e]	1.93	30	$\sim 10^5$	111
^{194}Pt	192 ± 25 [f]	1.89	30	$\sim 10^5$	90.2
^{196}Pt	$>1.35 \times 10^5$ [g]	1.94	30	$\sim 10^5$	13.9

[a] See Refs. 15 and 21.
[b] See Ref. 2.
[c] This work.
[d] Taken from Ref. 13.
[e] Taken from Refs. 11, 13, 16, 17, and 19.
[f] Taken from Refs. 11, 18, and 20.
[g] Taken from Refs. 11, 15, and 18.

both the prolate minimum and the oblate minimum so that two excited 0^+ states would be expected. Under the circumstances of the platinum isotopes these 0^+ states would be strongly mixed. Therefore, these might be recognized by strong transitions between them. The confirmation of higher 0^+ states such as we have suggested for ^{186}Pt and ^{188}Pt would be of great interest.

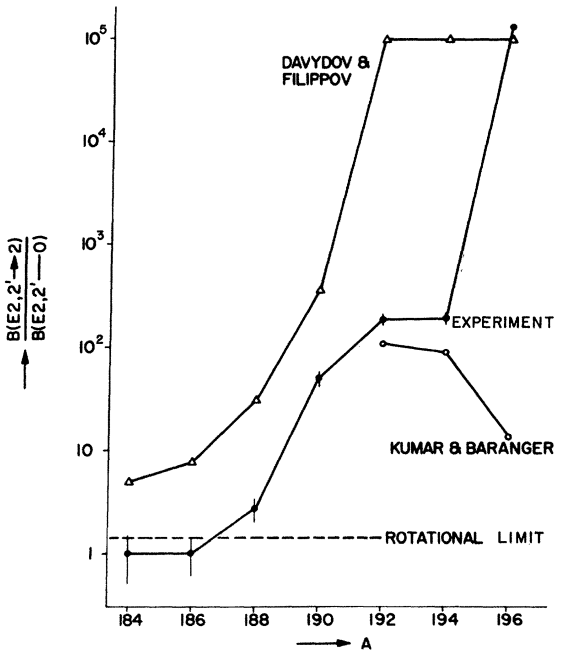

FIG. 11. $B(E2)$ ratios for even-even Pt isotopes, $R = B(E2, 2^{+\prime} \rightarrow 2^{+})/B(E2, 2^{+\prime} \rightarrow 0^{+})$. References are given in Table VIII.

The experimental $B(E2)$ ratios $R = B(E2, 2^{+\prime} \rightarrow 2^{+})/B(E2, 2^{+\prime} \rightarrow 0^{+})$ are available for the even-even isotopes $^{184-196}$Pt, and are listed in Table VIII. For pure rotational bands, the ratio R is given simply by a ratio of Clebsch-Gordon coefficients squared[22]

$$\frac{B(E2, 2^{+\prime} \rightarrow 2^{+})}{B(E2, 2^{+\prime} \rightarrow 0^{+})} = \frac{\langle I_i L K_i \Delta K | I_f K_f \rangle^2}{\langle I_i L K_i \Delta K | I_f K_f \rangle^2} = 1.43 \ .$$

In the harmonic-oscillator description, on the other hand, the $2^{+\prime}$ state can be interpreted as a two-phonon excitation and, hence, the cross-over $2^{+\prime} \rightarrow 0^{+}$ transition is strictly forbidden. The experimental values indicate that for $^{184-188}$Pt R is close to the rotational limit whereas for ^{196}Pt it is that for a good vibrator.

The experimental $B(E2)$ ratios are compared in both Table VIII and Fig. 11 with the predictions of the asymmetric-rotor model[21] and to those of Kumar and Baranger.[2] The values of the asymmetry parameter γ of the former model are derived from the energy ratios $E(2^{+\prime})/E(2^{+})$, and are used to obtain the theoretical values for the ratio R.[21] Following Ikegami *et al.*[15] we use $R \approx 10^5$ for $\gamma = 30°$. Neither set of theoretical values accurately reproduces the experimental values, although the Davydov and Filippov[21] model does qualitatively indicate the trend of the experimentally observed values.

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