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Onset of Collectivity in Neutron Deficient ^{196,198}Po

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Abstract

We have studied via in-beam γ-ray spectroscopy ^{196}Po and ^{198}Po, which are the first neutron-deficient Po isotopes to exhibit a collective low-lying structure. The ratios of yrast state energies and the E2 branching ratios of transitions from non-yrast to yrast states are indicative of a low-lying vibrational structure. The onset of collective motion in these isotopes can be attributed to the opening of the neutron $i_{13/2}$ orbital at N≈112 and the resulting large overlap between the two valence protons in the $h_{9/2}$ orbital and the valence

neutrons in the $i_{13/2}$ orbital.

27.80.+w, 21.10.Hw, 21.10.Re, 21.60.Cs, 21.60.Ev, 23.20.En, 23.20.Lv

I. INTRODUCTION

The polonium isotopes, with two valence protons beyond the closed Z=82 core, provide an excellent laboratory in which to study the transition between single-particle and collective behavior in a nuclear system. The low-lying structure and energy spacings in ^{210}Po with N=126 can be described by two $h_{9/2}$ protons in spherical shell models. As the number of neutrons decreases, the large number of valence particles makes a shell model description of the low-lying structure less meaningful and the onset of a collective structure in the low-lying states is expected.

However, the type of collective motion that occurs is an open question. One possibility, due to the small number of valence protons, is a vibrational spectrum. Vibrational systems are characterized by equal energy spacings, nearly degenerate phonon multiplets, and $\Delta N_{ph} = \pm 1$ E2 selection rules, where N_{ph} is the number of phonons for that state. A second possibility has been suggested in earlier studies [1,2] of the Po nuclei. As the middle of the neutron shell is approached, a 4 particle-2 hole (4p-2h) excitation, in particular the $(\pi h_{9/2})^4(\pi s_{1/2})^{-2}$ excitation, could play an important role in Po nuclei, just as evidence for 2p-2h proton excitations is observed in the Pb isotones [2]. The 4p-2h configuration has a larger effective proton valency and is expected to be moderately deformed. One signature of a 4p-2h structure is strong E0 transitions to the "normal" $(\pi h_{9/2})^2$ structure, which occurs when there is mixing between "normal" and 4p-2h configurations. The exact form of collectivity and the degree to which it persists as a function of excitation energy and angular momentum will be strongly influenced by the nature of the orbitals located near the Fermi surface, which are displayed in Fig. 1. As we shall show, the unique-parity $\nu i_{13/2}$ orbital plays a major role in the collectivity as the more neutron-deficient nuclei near N $\approx$ 112 are considered.

II. EXPERIMENTS

We have performed two measurements of ^{196}Po. Initially, the ^{172}Yb(^{28}Si,4n) reaction was studied at the Argonne Tandem - Linear Accelerator System (ATLAS) facility, with beam energies of 141 and 145 MeV, using an enriched ^{172}Yb target ($\approx$1mg/cm^2) on a $\approx$10 mg/cm^2 Pb backing. The Argonne-Notre Dame BGO facility was used. This array consists of 12 Compton-suppressed Ge detectors and a 50-element Bismuth-germanate (BGO) inner array. Approximately 35 million γ-γ events, with an inner array multiplicity K$\geq$2 and at least 2 suppressed Ge detectors, were recorded to tape. The data were sorted off-line into several matrices, of which the one with K$\geq$5 was used for the majority of the analysis. This minimized the contributions from Coulomb excitation and particle transfer channels in the data. An example of a coincidence spectrum is presented in Fig. 2, which displays the spectrum gated on the 463-keV $2^+ \rightarrow 0^+$ transition. Spin assignments were determined through the use of Directional Correlations of gamma rays from Oriented nuclei (DCO) ratios. The definition of the DCO ratios for the Argonne ^{196}Po data is given in Ref. [4]. Table 1 summarizes the results for the γ rays in ^{196}Po determined from the ANL data set; complete details of the analysis are given in Ref. [5]. The 5^- spin-parity assignment to the 1802-keV level is based on systematics and the stretched dipole character of the 414-keV line.

In a second experiment at the 88" Cyclotron at Lawrence Berkeley Laboratory, ^{196}Po was also produced with the same reaction and a 142 MeV ^{28}Si beam. The target consisted of two thin ($\approx$500μg/cm^2) ^{172}Yb foils. The High Energy Resolution Array (HERA), which consisted of 20 Compton-suppressed Ge detectors and a 40 element BGO inner ball, was used for spectroscopy. Approximately 65 million doubly-coincident events were recorded to tape. The results of the initial analysis confirmed the level scheme obtained from the ANL experiment. A "triples matrix" was then constructed from all triple and higher fold events; for each sorted event two γ rays assigned to ^{196}Po from the ANL data set were required. Pairs of coincidence gates were used to place a higher spin, non-yrast band which could

not be separated from competing channels in the ANL data. The level spectrum of ^{196}Po deduced from both of our data sets is displayed in Fig. 3.

Also at the LBL 88" cyclotron ^{198}Po was studied via the ^{174}Yb(^{29}Si,5n) reaction with 141 and 146 MeV beams and the HERA spectrometer. Both thin (three stacked $\approx$500μg/cm^2 foils) and thick ($\approx$1mg/cm^2 on $\approx$12 mg/cm^2 Au backing) enriched ^{174}Yb targets were used. The data were sorted into two matrices, with cuts on the inner-ball fold of K>6 and K>11. A normalized subtraction of these matrices allowed for separation of the 5n (^{198}Po) and 4n (^{199}Po) channels. An extensive level scheme up to $E_x \approx 5.1$ MeV and J$\approx$20$\hbar$ was deduced and will be reported on elsewhere [5]. Concurrent results [6] by M. Lach *et al.*, on levels in ^{198}Po have been recently reported.

III. RESULTS

A. ^{196}Po

Earlier work by Alber *et al.* [1], studied the delayed γ rays depopulating the 850-ns 11^- isomer in ^{196}Po. As summarized in Fig. 3, this level scheme has been extended via the first in-beam spectroscopy measurements in this nucleus and spins and probable parities of the levels have been determined using the ATLAS data. Most of the results of the isomer decay study have been confirmed in the present study, with the exception of the proposed direct decay from the isomer to the negative-parity states. The 552- and 198-keV lines proposed in the decay study of Ref. [1] were not observed. Since both the 237- and 253-keV transitions, and not the 552-keV $11^- \rightarrow 8^+$ transition which directly depopulates the isomer, are clearly evident in Fig. 2, it can be inferred that both the 237- and 253-keV lines must be prompt and neither of them depopulates the isomer directly.

Our prompt spectroscopy has also yielded two new branches which bypass the 11^- isomer. The first cascade consists of 4 transitions up to J=13$\hbar$ and is connected to the yrast 6^+ and 8^+ states via two γ rays, 584 and 652 keV, respectively. The second extension is a sequence

of 3 mutually coincident transitions feeding into the 7^-, 9^- and (10^+) states. This cascade was found in the LBL data in spectra that were double-gated on known low-lying transitions in ^{196}Po. Since this band could only be identified using a sum of doubly-coincident gates on the 237, 253, 414, and 529 keV lines, no multipolarity information for this cascade could be determined. The new lines did not have sufficient intensity to extract DCO ratios from the ANL DCO data. We have also added two new levels above the 9^- state at 2292 keV.

The 2_2^+ and 4_2^+ states are of particular interest in the low-lying level scheme. They feed into the yrast cascade via the 396- and 497-keV ΔJ=0 transitions, respectively. We summarize in Table 2 the relative intensities for transitions in the $4_2 \rightarrow 4_1 \rightarrow 2_1$ and the $2_2 \rightarrow 2_1 \rightarrow 0$ cascades. These values were determined from ANL spectra gated on the 414- and 529- keV lines which directly feed the 4_2^+ and 2_2^+ levels, respectively. Within the statistical uncertainties the intensities of the transitions in these cascades are identical and there is no indication in either of our data sets of any missing γ-ray intensity in the ΔJ=0 transitions, and hence no measureable evidence for E0 components. This is in contrast to the analysis of Ref. [1], which claimed to see intensity imbalances, although no supporting data were presented.

B. ^{198}Po

The nucleus ^{198}Po was previously investigated in Refs. [1,6]; the level scheme we have deduced for the low-lying levels agrees with the earlier work. The low-lying level spectrum is very similar to that of ^{196}Po in that there is an yrast cascade of similarly spaced γ rays, as well as non-yrast 2_2^+ and 4_2^+ levels which feed into the yrast branch via ΔJ=0 transitions. We summarize in Table 2 the relative intensities for transitions in the $4_2 \rightarrow 4_1 \rightarrow 2_1$ and the $2_2 \rightarrow 2_1 \rightarrow 0$ cascades in ^{198}Po. These values were determined from spectra gated on the 391- and 444-keV lines which directly feed the 4_2^+ and 2_2^+ levels, respectively. As with ^{196}Po, no clear evidence was found for missing intensity in the ΔJ=0 transitions, and hence no evidence for measureable E0 components. This result is in contrast to previous [1]

measurements of ^{198}Po. The analysis reported in Ref. [1] indicated $\alpha_{\rm tot}$ ($2_2 \rightarrow 2_1$ transition) $\geq$2 and most likely $\alpha_{\rm tot} \approx 5$. Our data show no statistically significant intensity imbalance; given our error bars we extract $\alpha_{\rm tot}$ <2. The $\alpha_{\rm tot} = 0.52(23)$ for the $2_2 \rightarrow 2_1$ line deduced in Ref. [1] is small and not that different from the expected value for an M1 transition. Again our data show no statistically significant intensity imblance and within our error bars $\alpha_{\rm tot}$ <0.6.

IV. DISCUSSION

The systematics of the even-even Po nuclei is displayed in Fig. 4. The heavier isotopes (A>200) have remarkably similar yrast 2^+, 4^+, 6^+ and 8^+ energy spacings, with low-lying 2^+ states and closely spaced 6^+ and 8^+ levels. However, a change is evident in the vicinity of A$\approx$198. A simple way of examining the low-lying structure of a nucleus is to consider the ratio of the yrast state energies. ^{210}Po, which is semi-magic with N=126, has a ratio of the yrast 4^+ and 2^+ energies, R(4/2) = 1.21. This is precisely what is predicted for a two-particle system with a residual surface-delta interaction [9]. In a vibrational system, the expected value for R(4/2) is 2.0. All of the Po nuclei from ^{206}Po$_{122}$ to ^{196}Po$_{112}$ exhibit R(4/2) values close to 2. This is a strong indication that the states up to J=4 have dominant vibrational character almost as soon as the neutron shell is opened. On the other hand, the close spacing between the 6^+ and 8^+ states suggest dominant $(\pi {\rm h}_{9/2})^2$ components.

The transition to collectivity for the higher spin states (J > 4) occurs deeper in the neutron shell, near N=112. Two features are distinctive in the low spin level schemes of ^{196}Po and ^{198}Po, as seen in Fig. 4. The first is the almost equal spacing between the yrast 0^+, 2^+, 4^+ and 6^+ levels. The second is the non-yrast 4_2^+ and 2_2^+ states, which in ^{196}Po are nearly degenerate with the yrast 6^+ and 4^+ states, and form structures which are reminiscent of 3- and 2-phonon multiplets, respectively. In addition, ^{198}Po is the first nucleus in the isotopic chain to show a decrease in the yrast 6^+ energy. In ^{196}Po the 6^+ energy has dropped an additional 327 keV to a point located almost exactly half-way between the yrast 4^+ and 8^+

states. These features combine to form a low-lying level scheme in ^{196}Po that is a classic example of a vibrational structure.

The yrast energy ratios for ^{196,198,200}Po are summarized in Table 3. In Po the valence protons are in the $h_{9/2}$ orbital, with a maximum coupled angular momentum of 8. Therefore, to examine the limits of low-lying collective motion in Po, the ratios of the higher spin yrast levels, such as R(6/4) and R(8/6) should be considered. The predictions of energy ratios for $(\pi h_{9/2})^2$, harmonic vibrational, and rotational models are also listed in Table 3. The data for both ^{196}Po and ^{198}Po are clearly best reproduced by the vibrational expectations, even up to the R(8/6) ratio in ^{196}Po. In contrast, in ^{200}Po the energy ratios for the higher spin states favor a two-proton configuration. The difference in the collectivity of the 6^+ states in ^{198}Po and ^{200}Po is also supported by the absolute B(E2) values. The B(E2; $8^+ \rightarrow 6^+$) value [6] in ^{198}Po is significantly smaller than in the heavier isotopes, which indicates a structural difference between these 8^+ and 6^+ states, and probably a more collective nature for the 6^+ level in ^{198}Po.

The branching ratios of transitions depopulating the low-lying states also probe the nature of the excitation. If the low-lying structure in ^{198,196}Po is vibrational, then the selection rule $\Delta N_{ph} = \pm 1$ for E2 transitions between phonon multiplets should be valid. Although no absolute B(E2) values were obtained in the present measurements, the ratio of B(E2) values can be calculated from the ratio of the γ-ray intensities of the two depopulating transitions as seen in a coincidence gate placed on a γ-ray feeding the level of interest. The assumption is made that the observed $\Delta J=0$ transitions are of pure E2 character. This is a reasonable assumption because in the Pb isotones the analogous transitions have small M1 components [2]. The comparisons between experimental values and the theoretical predictions for a vibrational, rotational, and a 4p-2h configuration are given in Table 4 for both ^{198}Po and ^{196}Po. For the vibrational limit, the branching ratios are based on the coefficients of fractional parentage, which govern the wave functions of the members of the phonon multiplets. For the rotational limit, transitions out of the band are forbidden. Typically, these "forbidden" transitions are 20-50 times weaker than the allowed branches. If

the non-yrast states are members of a 4p-2h configuration, then, to first-order, they will not interact with the normal two-proton configurations via the one-body E2 or M1 operators. However, E0 transitions are expected if there is any mixing between the spherical 2p, and more deformed 4p-2h, configurations, due to the difference in their radii. In the present data, E0 components in the transitions between the "normal" and 4p-2h states would be signaled by missing gamma-ray intensity in the ΔJ=0 transitions. Large E0 components (ρ^2(E0) $\leq$ 7x10^2) are seen in the decay of the 2_2^+ states in the Pb isotones [2]. In contrast, our data, summarized in Table 2, show no clear evidence for missing intensity in any of the ΔJ=0 transitions depopulating the non-yrast 4_2^+ and 2_2^+ states in either ^{198}Po or ^{196}Po. As displayed in Tables 3 and 4, the relative B(E2) ratios of the non-yrast transitions, together with the energy spacings, are only consistent with a vibrational collective structure for these low-spin excitations in ^{196,198}Po.

To summarize, the energy level and branching ratio data support the existence of vibrational collectivity in the Po isotopes which persists to moderate angular momentum in ^{196,198}Po. To obtain a more microscopic understanding of the onset of collective vibrational structure at ^{198,196}Po, we shall consider next the underlying single particle structure.

V. SINGLE-PARTICLE INTERPRETATION

Collectivity is a result of interactions between valence protons and neutrons which occur when there is significant overlap between their respective wavefunctions. When this overlap is large, mixing occurs which results in the lowering in energy of a coherent, collective state. The yrast, low-lying levels in the semi-magic ^{210}Po nucleus are known to consist predominantly of a simple $(\pi h_{9/2})^2$ structure. The neutrons are the hole orbitals given in Fig. 1 below the N=126 gap: $p_{1/2}$, $p_{3/2}$, $f_{5/2}$, and $i_{13/2}$. A necessary condition for good overlap between the valence protons and neutrons is that the angular behavior of the wavefunctions is similar.

Schiffer [9,10] developed a simple way to quantify semi-classically the amount of angular

overlap between single-particle wave functions. When two angular momentum vectors, j_1 and j_2, are added to form a resultant, J, the three vectors obey the law of cosines, which can be written as

$$\theta_{j_1,j_2,J} \;=\; \cos^{-1}\left\{\frac{J^2 - j_1^2 - j_2^2}{2|j_1|\;|j_2|}\right\} \tag{1}$$

If the vectors are replaced with operators and the expectation value of the operators are extracted then, for $j = j_1 = j_2$

$$\theta_{j,J} \;=\; \cos^{-1}\left\{\frac{J(J+1) - 2j(j+1)}{2j(j+1)}\right\} \tag{2}$$

This "semi-classical" angle can be viewed as the angle two particles in the same orbital, j, make with respect to one another in order to form the total angular momentum, J, of a given state. It gives a quantitative measure of the distribution in angles of the nucleons in a state with a particular J.

Table 5 presents the semi-classical angles of several $|(j)^2,J>$ configurations located near the Fermi surface in ^{196,198}Po. The angles for the neutron $(i_{13/2})^{-2}$ and proton $(h_{9/2})^2$ configurations up to moderate angular momentum are similar. This is consistent with our assumption of collective motion that persists up to at least J≈6 when the $\nu i_{13/2}$ orbital is near the Fermi surface.

The following then summarizes our understanding of the onset of collectivity in Po nuclei as a function of neutron number and angular momentum. The 2_1^+ level becomes collective as soon as there are valence neutrons. By N≈122 with the opening of the $2f_{5/2}$ orbital, the 4_1^+ state also has a predominantly 2-phonon collective character. As N=112 is approached, vacancies in the $i_{13/2}$ orbital occur, which allow two-neutron configurations with J>4. Given the sizable angular overlap in the $(\nu i_{13/2})^{-2}$ and $(\pi h_{9/2})^2$ wavefunctions, collectivity persists beyond J=4, with a predominantly collective 6_1^+ state and, possibly less collective, 8_1^+ state. Vibrational collectivity also characterizes the low-spin non-yrast states in ^{196,198}Po.

VI. CONCLUSION

Evidence of collective vibrational motion that persists to moderate angular momentum has been observed in the low-lying structure of ^{196}Po. The energy spacings of the yrast 2^+, 4^+, 6^+ and, possibly, 8^+ states, as well as of the 2_2^+ and the 4_2^+ levels, are consistent with the spacings of one, two, three, and possibly four, phonon multiplets. The ratios of the B(E2) values for decays from the 4_2^+ and 2_2^+ states are also consistent with those of a vibrational structure. The branching ratios, together with the lack of a measureable intensity imbalance for the ΔJ=0 transitions, indicate that it is unlikely that a 4p-2h proton configuration plays a significant role in the non-yrast states. The transition at J $>$ 4 from single-particle behavior in ^{200}Po to collective behavior in ^{196}Po can be attributed to the opening of the $i_{13/2}$ neutron orbital, which allows neutron configurations of higher spin to interact with the $h_{9/2}$ protons to form collective states. A more quantitative interpretation of these nuclei could come from a more detailed analysis of the interaction between vibrational phonons and the two valence protons, for example, within the particle-core coupling model [11]. Such calculations are in progress [12] and preliminary results confirm our naive interpretation that ^{200}Po has little collectivity for J$>$4, ^{196}Po is an excellent multi-phonon vibrator, and that ^{198}Po is intermediate, with wave functions which reflect a complicated interplay between collective and two-proton configurations for J$>$4 excitations.

The present analysis has focused on relatively limited measures of collectivity, i.e., energy levels and relative B(E2) values. A definitive measure of the collectivity as a function of neutron number and angular momentum can come from absolute B(E2) values. However, these values are difficult to obtain from Doppler effects because of the plethora of isomers in the level schemes of these polonium isotopes with only a few valence particles.

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FIGURES

FIG. 1. Energy levels for protons and neutrons in ^{208}Pb, taken from Ref. [3].

FIG. 2. Coincidence spectrum gated on the 463-keV, $2 \rightarrow 0$ transition in ^{196}Po from the ANL measurements of the ^{172}Yb(^{28}Si,4n) reaction at 141 and 145 MeV. A multiplicity requirement K$\geq$5 was applied to the coincidence matrix.

FIG. 3. Level scheme of ^{196}Po obtained from the present measurements. The widths of the arrows are proportional to the γ-ray intensities. The 11^- isomeric state was taken from Ref. [1]. The de-exciting transition from this isomer were not observed in the present measurements, as indicated by the dotted line.

FIG. 4. Even mass polonium systematics from ^{210}Po (N=126) to ^{196}Po (N=112), taken from Refs. [1,6–8] and the present work.

TABLES

TABLE I. Energies, relative intensities and DCO ratios for the γ rays in ^{196}Po from the ^{172}Yb(^{28}Si,4n) reaction measured at ANL.

Energy (keV)	Intensity	DCO ratio	Multipolarity
237.28(9)	29.0(4)	1.26(35)	E2
253.45(10)	30.8(4)	1.16(39)	E2
387.64(12)	46.8(6)	0.75(25)	(E1)
395.82(12)	13.1(4)	1.44(31)[a]	
414.24(8)	44.8(8)	0.88(33)	E1
427.89(9)	94.7(10)	1.24(15)	E2
463.09(9)	≡100	1.41(14)	E2
485.79(10)	18.9(4)	0.82(60)[b]	(E1)
496.74(10)	18.5(4)[c]		
499.11(10)	69.7(7)	1.48(26)	E2
528.61(11)	15.2(6)	1.44(36)	E2
550.29(11)	20.9(21)	1.39(51)	E2
565.3(2)	8.17(24)	1.34(41)[b]	E2
583.9(2)	51.7(7)	1.96(54)	E2
616.9(2)	43.7(8)	1.68(24)	E2
651.3(2)	6.9(8)[c]		
667.7(2)	41.6(10)	1.70(41)	E2
859.2(2)	20.5(7)	1.33(60)[b]	E2
911.5(3)	20.1(6)[c]		

[a]The LBL data indicates that the ≈396-keV line is contamainated with another γ ray that was not placed in the level scheme. Therefore, no multipolarity assignment was made for the transition placed with the ANL data.

[b]DCO ratio obtained from a sum gate on the 237 + 253 keV lines.

[c]Insufficient intensity to extract the DCO ratio.

TABLE II. Intensities of transitions in the $4_2^+ \rightarrow 4_1^+ \rightarrow 2_1^+$ and $2_2^+ \rightarrow 2_1^+ \rightarrow 0$ cascades in ^{196,198}Po. In ^{196}Po the intensities were determined in coincidence spectra gated on the 414 keV $5^- \rightarrow 4_2^+$ and 529 keV $4_2^+ \rightarrow 2_2^+$ transitions, respectively. In ^{198}Po the intensities were determined in similar spectra gated on the 391 keV $6_2^+ \rightarrow 4_2^+$ and 444 keV $4_2^+ \rightarrow 2_2^+$ transitions, respectively.

Nucleus	Gate	$I_\gamma(2_2^+ \rightarrow 2_1^+)$	$I_\gamma(2_1^+ \rightarrow 0_1^+)$
^{196}Po	529 keV	91(21)	73(21)
^{198}Po	444 keV	89(31)	100(31)
Nucleus	Gate	$I_\gamma(4_2^+ \rightarrow 4_1^+)$	$I_\gamma(4_1^+ \rightarrow 2_1^+)$
^{196}Po	414 keV	59(22)	44(24)
^{198}Po	391 keV	51(26)	100(23)

TABLE III. Energy ratios of yrast states in ^{196,198,200}Po compared to the theoretical predictions for $(h_{9/2})^2$, vibrational, and rotational models. The $(h_{9/2})^2$ predictions are for a surface delta interaction.

	R(4/2)	R(6/4)	R(8/6)
^{200}Po	1.92	1.38	1.01
^{198}Po	1.91	1.48	1.08
^{196}Po	1.92	1.56	1.39
$(\pi h_{9/2})^2$	1.17	1.07	1.03
Vibrational	2.00	1.50	1.33
Rotational	3.33	2.10	1.71

TABLE IV. Comparison between experimentally deduced E2 branching ratios depopulating the non-yrast 2_2^+ and 4_2^+ states and theoretical predictions for rotational, vibrational and 4p-2h models. The experimental transitions are assumed to be of pure E2 character; the experimental errors given in parentheses are on the last digit(s). The rotational predictions assume K=0 for both quasibands.

		B(E2) Ratios			
Nucles	Transition	Experiment	Vibrator	Rotor	4p-2h
^{196}Po	$4_2^+ \to 2_2^+$ / $4_2^+ \to 4_1^+$	1.0(5)	1.10	> 20	> 20
^{196}Po	$2_2^+ \to 2_1^+$ / $2_2^+ \to 0_1^+$	64(14)	∞	2.04 (K=0)	Large E0
^{198}Po	$4_2^+ \to 2_2^+$ / $4_2^+ \to 4_1^+$	2.0(5)	1.10	> 20	> 20
^{198}Po	$2_2^+ \to 2_1^+$ / $2_2^+ \to 0_1^+$	158(6)	∞	2.04 (K=0)	Large E0

TABLE V. Values of semi-classical angles (in degree) of $|(j)^2J>$ configurations for valence orbitals in polonium nuclei. See text for details.

j (single particle)	J=2	J=4	J=6	J=8
$i_{13/2}$	160	144	127	108
$h_{9/2}$	152	127	99	63
$f_{5/2}$	131	82	–	–
$p_{3/2}$	90	–	–	–