Shape coexistence of high-spin isomeric states in proton-rich $A\sim190$ nuclei *

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Abstract High-spin isomeric states in proton-rich $A\sim190$ nuclei have been investigated using configuration-constrained calculations of potential-energy surfaces. The calculations reproduce reasonably the experimental data, and predict shape coexistence of high-spin isomeric states in light Po isotopes.

Key words high-spin isomer, shape coexistence, configuration-constrained calculation

PACS 21.10.-k, 21.60.-n, 23.20.Lv

1 Introduction

Proton-rich $A\sim190$ mass region is characteristic of shape coexistence. In this mass region, there exists rare coexistence of triple shapes: sphere, oblate and prolate[1]. More interesting shape coexistence is predicted in light Po nuclei[2]. Here it is shown in Ref.[2] that small prolate (SP), large prolate (LP), small oblate (SO) and large oblate (LO) shapes may coexist. Experiments observed high-spin isomers having various shapes in proton-rich $A\sim190$ nuclei[3]. For example, in ^{188}Pb, there exist a spheric 12^+ isomer, an oblate 11^- isomer and a prolate 8^- isomer[4]. However, there has been no observation of shape coexistence of high-spin isomeric states. Theoretically, it is predicted that light Po isotopes may show small oblate and large oblate coexistence of 11^- isomeric states[2]. In the present work, we investigate such interesting phenomenon using configuration-constrained calculation of potential-energy surface (PES)[5].

2 The model

In the configuration-constrained PES calculation, single-particle levels are obtained by the nonaxial Wood-Saxon potential[6]. Pairing is treated using the Lipkin-Nogami method[7] that can approximately conserve the particle number. The monopole pairing strength (G) is first determined by the average gap method[8], and then adjusted through the reproduce of experimental odd-even mass difference (see Ref. [5] for the detail of the G adjustment). The total energy consists of macroscopic and microscopic parts. The former is calculated by the standard liquid drop model[9], and the latter is obtained through the Strutinsky shell correction[10]. The configuration-constrained method allows the calculation of PES for a specified configuration. This is achieved by calculating and identifying the average Nilsson quantum numbers for every orbital involved in the configuration[5]. The calculation can properly treat the shape polarization due to unpaired nucleons.

In addition, the intrinsic quadrupole moment (Q_0) of a specified configuration is calculated by $Q_0=\sum_{j=1}^{S}q_{k_j}+\sum_{k\neq k_j}2V_k^2q_k$ (where q_k is the single-proton quadrupole moment obtained from the Woods-Saxon wave function and S is the number of the blocked orbitals with index k_j). For axial deformation, a mea-

Received 8 July 2008
* Supported by National Natural Science Foundation of China (10735010, 10525520, 10475002) and the Chinese Major State Basic Research Development Program (2007CB815000)
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sured spectroscopic quadrupole moment (Q_s) is transformed to Q_0 through the relation $Q_0 = Q_s[(2I+3)(I+1)]/[3K^2 - I(I+1)]$.

3 Calculations and discussions

In Fig. 1, we display the calculated $11^-\{\pi9/2^-[505] \otimes \pi13/2^+[606]\}$ isomeric states in Pb and Po isotopes and their comparison with experiments[3, 11]. One can see that the calculated excitation energies deviate considerably from the experimental data. This is because the proton Fermi surfaces of the nuclei are at or near the $Z = 82$ shell closure, which prohibits the adjustment of G due to the influence of shell gap on the odd-even mass difference. It has been shown in Ref.[5] that the adjustment of G is important for the reproduce of multi-quasiparticle state excitation energy. However, our calculations reproduce the variation trend of the excitation energies along both Pb and Po isotopic chains. The calculated quadrupole moment of 11^- isomer in ^{196}Pb is in good agreement with experiment, while our calculation for ^{194}Pb is remarkably underestimate the measured data. In Ref. [11], several calculations can reproduce well the quadrupole moment of the 11^- isomer in ^{196}Pb, but all the calculations give results for ^{194}Pb apparently smaller than experimental data. It is so far not clear why the theories can describe well one of two neighboring nuclei, but cannot describe well the other. Our calculations show coexistence of small oblate and large oblate 11^- isomeric states in light Po isotopes, which is consistent with the results of Ref. [2]. However, Ref. [2] gives almost constant and same excitation energies for both the small oblate and large oblate 11^- isomeric states, while there are variation with neutron numbers in our calculations (see Fig. 1). This can be clearly seen in Fig. 2 where we show the calculated PESs. Fig. 2 indicates that the 11^- isomeric states are reasonably stable against γ distortion.

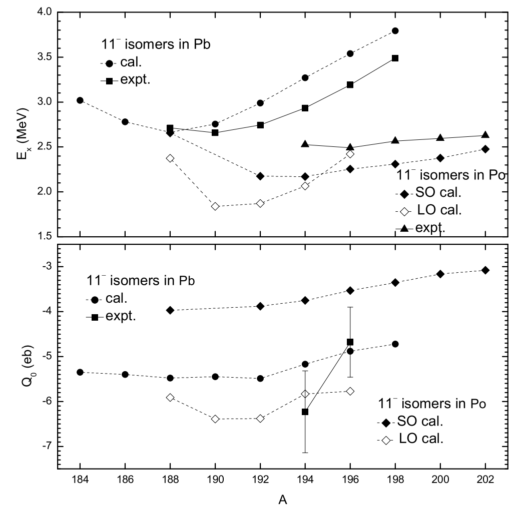

Fig. 1. Calculated excitation energies (upper panel) and intrinsic quadrupole moments (lower panel) of the 11^- isomeric states in Pb and Po isotopes. The experimental data are taken from Refs.[3, 11].

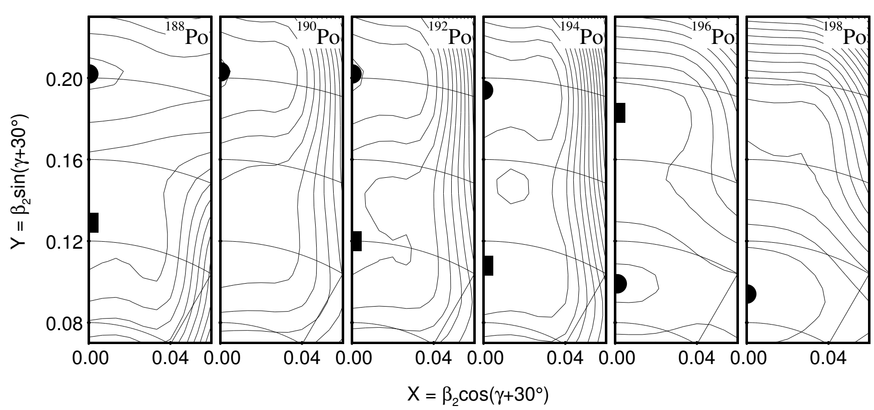

Fig. 2. Calculated PESs of the 11^- isomeric states in $^{188-198}$Po. The circles (squares) represent the first (second) minima. The energy interval between neighboring contours is 100 keV.

In ^{188}Po and ^{190}Po, we predict that large prolate high-spin isomeric state coexists with small prolate high-spin isomeric states (see Table 1), besides the coexistence of small and large oblate 11^- isomeric states. The large prolate 8^- isomeric configuration has been observed in $N = 106$ isotones from ^{174}Er to ^{188}Pb[12]. We list in Table 1 several proton-rich nuclei. The calculated excitation energies for these nuclei agree well with experiments. With the advance of experimental techniques, the 8^- state may also be

Table 1. Calculated $K^{\pi} = 8^{-}$ isomeric states in $N = 106$ isotones and $K^{\pi} = 6^{+}$ isomeric states in $N = 104$ isotones compared with experiments[12].

J^{π}	nucleus	β_2	$\|\gamma\|$	β_4	Q_0/(eb)	$E_{\text{cal.}}$/keV	$E_{\text{expt.}}$/keV
8^{-}_{LP}	$^{184}Pt_{106}$	0.231	0°	-0.030	7.25	1847	1839
	$^{186}Hg_{106}$	0.250	2°	-0.021	8.43	2271	2217
	$^{188}Pb_{106}$	0.264	0°	-0.017	9.30	2401	2578
	$^{190}Po_{106}$	0.276	0°	-0.010	10.74	2632	
8^{-}_{SP}		0.099	2°	0.013	3.52	2474	
6^{+}_{LP}	$^{182}Pt_{104}$	0.243	0°	-0.016	7.90	1806	
	$^{184}Hg_{104}$	0.252	2°	-0.007	8.53	1980	
	$^{186}Pb_{104}$	0.271	0°	-0.005	9.77	2074	
	$^{188}Po_{104}$	0.282	0°	0.003	11.07	2132	
6^{+}_{SP}		0.097	4°	0.015	3.49	2538	

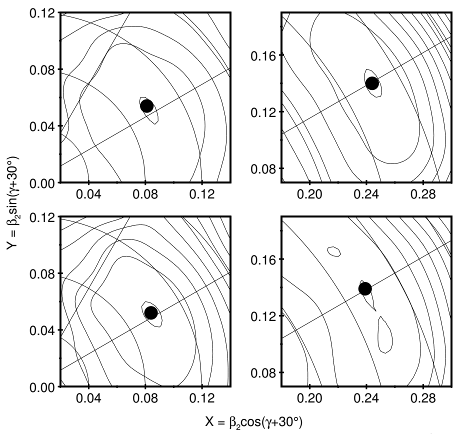

Fig. 3. Calculated PESs for the $K^{\pi} = 6^{+}$ isomeric states in ^{188}Po (upper panel) and the $K^{\pi} = 8^{-}$ isomeric states in ^{190}Po (lower panel). The left (right) PESs correspond to small (large) prolate shapes.

observed in ^{190}Po that only have two more protons than ^{188}Pb. It may be interesting that how the small prolate 8^{-} state influences the isomeric property of the large prolate 8^{-} state. In addition, we predict the existence of 6^{+} isomeric state in proton-rich $N = 104$ isotones. In $N = 104$ isotones with less protons, the isomer has been systematically observed[12]. The calculated PESs for the coexisting shapes in ^{188}Po and ^{190}Po are presented in Fig. 3.

4 Summary

Configuration-constrained PES calculations are performed for the investigation of high-spin isomeric states in proton-rich $A \sim 190$ nuclei. We predict shape coexistence of high-spin isomeric states in light Po isotopes. It is shown that small and large oblate 11^{-} isomeric states coexist in $^{188-196}$Po, and small and large 8^{-} (6^{+}) isomeric states coexist in ^{190}Po (^{188}Po).

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