Vol 10 No 4, April 2001
1009-1963/2001/10(04)/0282-04

Chinese Physics

© 2001 Chin. Phys. Soc.
and IOP Publishing Ltd

THE NUCLEAR STRUCTURE AND BACKBENDING PHENOMENON FOR $^{114-130}$Xe ISOTOPES *

SHI ZHU-YI(石筑一)[a], LIU YONG(刘 庸)[b], and SANG JIAN-PING(桑建平)[c]

[a] *Department of Physics, Guizhou Institute for Nationalities, Guiyang* 550025, *China*

[b] *Institute of Particle Physics, Huazhong Normal University, Wuhan* 430079, *China*

[c] *Department of Physics, Wuhan University, Wuhan* 430072, *China*

(Received 29 March 2000; revised manuscript received 17 October 2000)

In view of interacting boson fermion formalism, a microscopic sdIBM-2 +2q.p. model is used to describe the ground-state band, β-band, γ-band and two-quasi-particle band for $^{114-130}$Xe isotopes. The theoretical investigations indicate that the backbending is caused by crossing of the two-quasi-proton band and the ground-state band. This result seems to provide a possible way for understanding the backbending phenomenon of $^{114-130}$Xe isotopes.

Keywords: sdIBM-2+2q.p model, high-spin states, microscopic investigation
PACC: 2100, 2700

I. INTRODUCTION

In medium and heavy mass regions, some investigations show that the nuclear structure makes a smooth transition from a spherical shape to a deformed one as the mass number increases.[1,2] So far, many works have investigated the structure and property of the high-spin states in order to get a better understanding of the mechanism of the backbending phenomenon[1,3,4].

As far back as 1983, attention was directed towards that phenomenon. The yrast band in even $^{122-130}$Xe isotopes exhibits experimentally the backbending phenomenon at the position of 10^+ or 12^+ levels. Their backbending phenomena are considered to be caused by the crossing of the two-quasi-particle band and the ground-state band. More recently, in Ref.[1] results were obtained for the interesting backbending phenomenon in $^{114-130}$Xe isotopes by using the effective two-body interactions of the "pairing plus quadrupole–quadrupole" type in valence nucleon space for protons as well as neutrons. The microscopic theory for high-spin states presented in Ref.[4] can explain the recent experimental results on normal, two-quasi-neutron and two-quasi-proton bands. It is suggested that the higher spin states in the yrast band are states of two-quasi-proton alignments. These results obtained support from the latest experimental data on ^{124}Xe,[5] but are contrary to the explanation in Ref.[1]. The success in Ref.[4] has motivated us to carry out further investigation on the property of nuclear structure for xenon isotopes.

II. THE APPROACH

We assume that a boson may be broken into two nucleons which occupy the intruder orbit $h_{11/2}$. All the other valence nucleons can form a collective core described approximately by the sdIBM-2. This is the so-called IBM-2+2q.p. model. The microscopic theory for high-spin states is simply obtained by applying the microscopic sdIBM-2 formalism to the IBM-2+2q.p. model. As a detailed description of the microscopic high-spin states theory can be found in Ref.[4], an outline is introduced briefly in the following.

Starting from the shell model configurations and valence nucleon effective interactions, the shell model Hamiltonian is assumed to be,

$$H_f = H_f^{(n)} + H_f^{(p)} + H_f^{(n,p)}. \tag{1}$$

By the generalized Dyson expansion technique, the microscopic structure of the s,d bosons in IBM-2 can be defined. Finally, the boson–fermion Hamiltonian describing the high-spin states can be obtained after s–d boson space truncation for the core has been made,

$$h = h_{\mathrm{IBM}-2} + h_f + V_{\mathrm{BF}} + h_{\mathrm{mix}}, \tag{2}$$

where $h_{\mathrm{IBM}-2}$ is the most general IBM-2 Hamiltonian; h_f is the effective fermion Hamiltonian restricted to a unique parity intruder orbit with spin $h_{11/2}$; V_{BF} is the boson–fermion interacting term; h_{mix} is the term of mixing the ground-state band and the two-quasi-particle state band.

*Project supported by the National Natural Science Foundation of the Education Department of Guizhou Province (Grant No. [2000]518).

In the calculations, the Hamiltonian h is diagonalized in boson space and the spectra of normal states are obtained. If the Hamiltonian h is diagonalized in the space of direct product of the state in IBM-2 and the state with two quasi-neutrons, the two-quasi-neutron state band can be obtained. The same approach can be used to discuss the spectra of the two-quasi-proton state band.

Ⅲ. CALCULATED RESULTS AND DISCUSSION

For xenon isotopes, the valence nucleon configurations are $(1g_{7/2},\ 2d_{5/2},\ 1h_{11/2},\ 2d_{3/2},\ 3s_{1/2})^4$ $(2d_{5/2},\ 1g_{7/2},\ 1h_{11/2},\ 3s_{1/2},\ 2d_{3/2})^{\mathrm{Nn}}$. With no loss of generality, the nucleons have been treated as particle-like: Nn=10,12,14,16,18,20,22,24,26. Parameters $g_0^{(\sigma)}$, $G_2^{(\sigma)}$, $K^{(\sigma)}$ (σ=n,p) and $K^{(\mathrm{np})}$ are the strength of the pairing force, the quadrupole pairing force, the quadrupole–quadrupole force for identical nucleons and the neutron–proton force of quadrupole–quadrupole type, respectively. The single-particle energies for open shells and the strength of nucleon–nucleon effective interactions are chosen as follows:

Table 1. Single-particle energies of the valence nucleon[2,4] (MeV).

nlj	$2d_{5/2}$	$1g_{7/2}$	$1h_{11/2}$	$3s_{1/2}$	$2d_{3/2}$	nlj	$1g_{7/2}$	$2d_{5/2}$	$1h_{11/2}$	$2d_{3/2}$	$3s_{1/2}$
Neutron	4.00	4.28	6.22	6.64	6.74	Proton	4.00	4.54	5.90	7.24	7.47

Table 2. The parameters of nucleon–nucleon effective interactions (MeV).

	$g_0^{(\mathrm{n})}$	$G_2^{(\mathrm{n})}$	$K^{(\mathrm{n})}$	$g_0^{(\mathrm{p})}$	$G_2^{(\mathrm{p})}$	$K^{(\mathrm{p})}$	$K^{(\mathrm{np})}$
114	0.0340	0.0259	0.0010	0.0290	0.0195	0.0780	0.0300
116	0.0328	0.0257	0.0010	0.0284	0.0185	0.0800	0.0270
118	0.0324	0.0260	0.0010	0.0280	0.0175	0.0820	0.0236
120	0.0386	0.0462	0.0010	0.0278	0.0170	0.0830	0.0178
122	0.0432	0.0555	0.0050	0.0276	0.0165	0.0840	0.0130
124	0.0450	0.0560	0.0180	0.0274	0.0150	0.0860	0.0100
126	0.0500	0.0625	0.0180	0.0274	0.0150	0.0860	0.0115
128	0.0525	0.0630	0.0220	0.0280	0.0140	0.0900	0.0135
130	0.0530	0.0720	0.0266	0.0274	0.0140	0.0900	0.0160

Both for the normal states and high-spin states of xenon isotopes, the calculated spectra reproduce the experimental data quite well. As the spectrum for $^{116-122}$Xe has been given in Ref.[4], here only the spectrum of ^{124}Xe is presented in Fig.1. For $^{114-130}$Xe isotopes, one can see that good agreement between the theoretical calculation and experimental data has been obtained in Fig.2. In Fig.3, the result of moment of inertia I and the square of the cranking frequency ω^2 are plotted for nuclei $^{114-130}$Xe, where I and ω^2 are defined as follows:

$$2I/\hbar^2 = \frac{4J-2}{E_J - E_{J-2}}, \tag{3}$$

$$\hbar^2\omega^2 = \frac{(J^2-J+1)(E_J - E_{J-2})}{(2J-1)^2}. \tag{4}$$

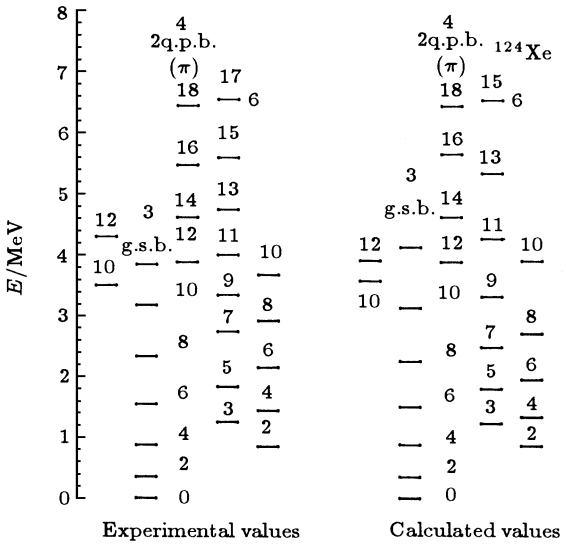


Fig.1. Comparison of the experimental and calculated spectra for ^{124}Xe. The experimental results and energy band labelled are taken from Ref.[5].

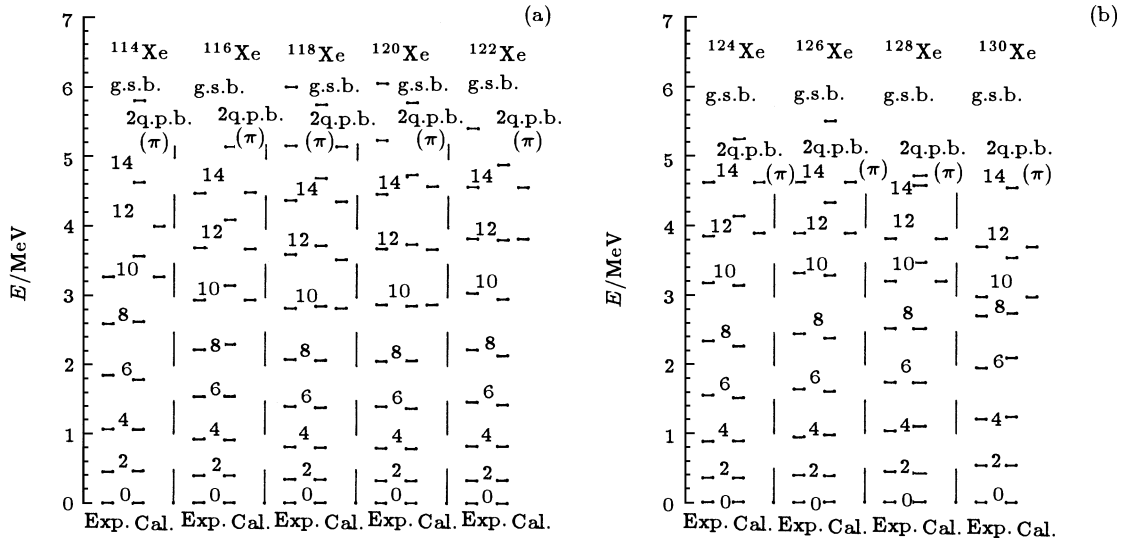


Fig.2. (a) Comparison of the experimental and calculated yrast spectra for $^{114-122}$Xe. (b) Comparison of the experimental and calculated yrast spectra for $^{124-130}$Xe. The experimental results are taken from Refs.[1,3,5,6].

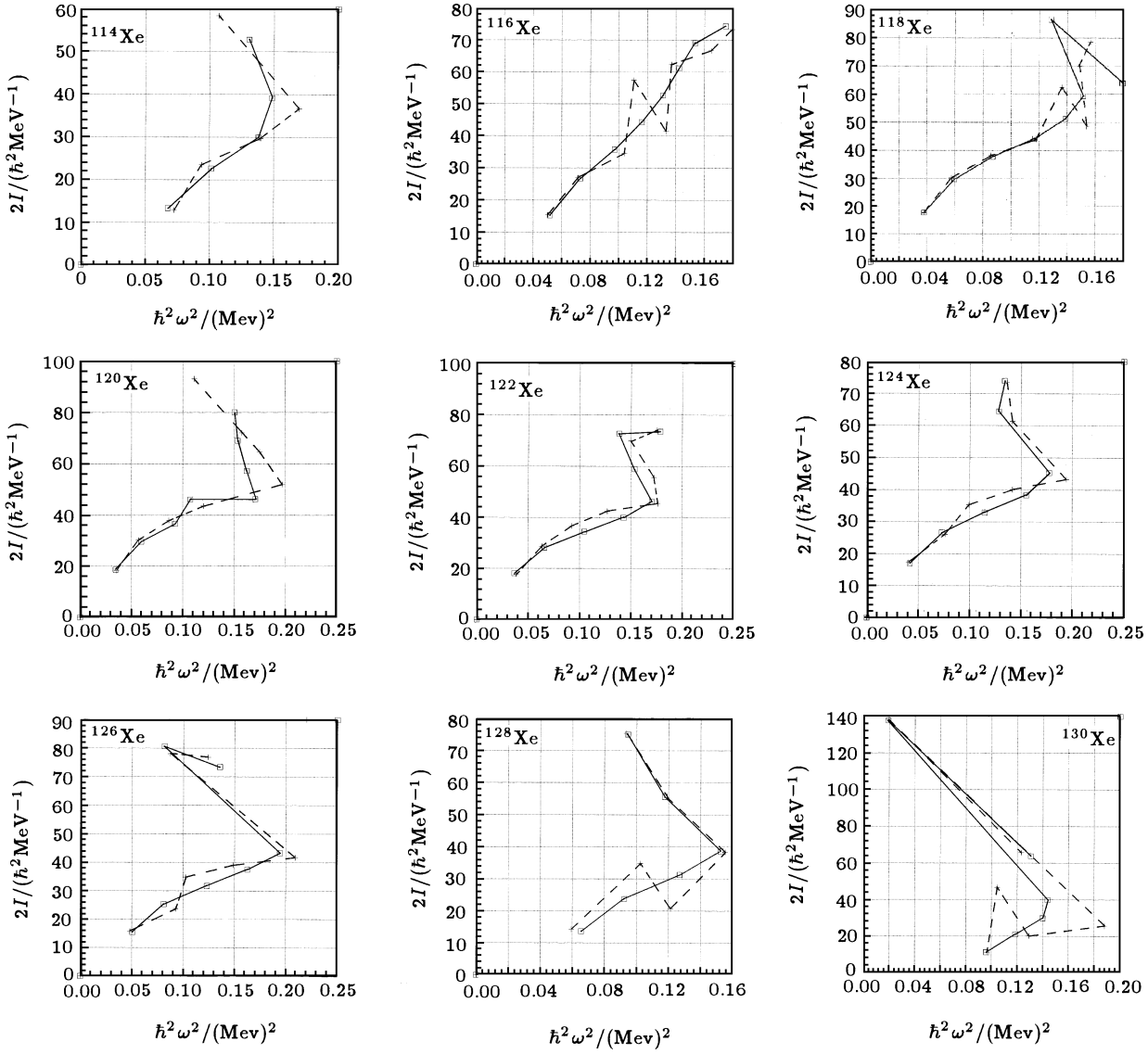


Fig.3. Comparison of the experimental (□) and calculated (+) $(1-\omega^2)$ plots for $^{114-130}$Xe. The experimental results are taken from Refs.[1,3,5,6].

The results show that the backbending phenomenon can be described by the approach used in this paper. For the nuclei exhibiting the backbending phenomenon, it is shown that the sdIBM-2 approach cannot reproduce the experimental results well around the backbending point; such as ^{114,128,130}Xe at J^{π}=10^{+}; ^{120,122,124,126}Xe at $J^{\pi} = 12^{+}$; ^{118}Xe at $J^{\pi} = 14^{+}$. But no backbending phenomenon occurred in ^{116}Xe. This is consistent with experimental observation. It reveals naturally that the backbending is caused by the crossing of the two-quasi-proton band and the ground-state band. Because of neutron excess, the Fermi surface of neutrons is closer to the $h_{11/2}$ Nilsson orbit than that of protons. So the two-quasi-proton alignment state is favourable in energy. This result has obtained verification in this paper and at the same time obtained support from the latest experimental data for ^{124}Xe in Ref.[5].

As the neutron number increases, the strength of effective interactions for neutrons changes gradually but the strength of effective interactions for protons keeps almost constant. The structure constants of bosons and some calculated energies change slightly. This is almost the same result as that in Ref.[4]. In the past, some works have shown that the nuclear structure changed greatly from ^{128}Xe to ^{130}Xe. But this situation does not happen in our work. The conclusion in Ref.[4] again obtains support here. Besides, the investigations in this paper and Ref.[4] show that the energy gap of single particle for valence nucleons is suitable for studying the nuclear structure. It could provide valuable single-particle energies to investigate the various excited states on adjacent nuclei.

IV. CONCLUSION

In summary, it is worth pointing out that the microscopic sdIBM-2 +2q.p approach is capable of describing both normal states and high-spin states for $^{114-130}$Xe isotopes. The theoretical calculations and analyses show that the backbending phenomenon may be the result of the crossing of the ground-state band and the band with two-quasi-protons occupying the intrude orbit $h_{11/2}$.

References

[1] Sarswat S P, Bharti A and Khost S K 1998 *Phys. Rev.* C **58** 2041, therein Refs.[1]–[13]

[2] Wang Y C, Liu Y and Qi H 1990 *High Energy Phys. Nucl. Phys.* **14** 274 (in Chinese)

[3] Kusakari H, Kitao K and Sato K *et al* 1983 *Nucl. Phys.* A **401** 445

[4] Shi Z Y, Liu Y and Sang J P 2000 *Chin. Phys.* **9** 9, therein Refs.[1]–[6]

[5] Schneider I, Chakrartly R S and Wiedenhover T *et al* 1999 *Phys. Rev.* C **60** 014312

[6] Sakai M 1984 *At. Data Nucl. Data Tables* **31** 399

[7] Jr. Mantica P F, Zimmerman B E, Walters W B and Rikovska J *et al* 1992 *Phys. Rev.* C **45** 1586