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Shape and alignment effects in Xe nuclei

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Abstract : Even mass Xe nuclei have received much attention recently. In this work we study the structures of even-even $^{118-126}$Xe nuclei by deformed Hartree-Fock and angular momentum projection The systematics of the alignments of $\pi h_{11/2}$ and $\nu h_{11/2}$ orbits are emphasised Some observations are made about the band structures of neighbouring odd mass xenon and iodine nuclei.

Keywords : Xe nuclei, shape and alignment effects, nuclear structure

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1. Introduction

Several features like shape changes, interplay of collective and single particle like behaviour, rotation alignment effects have been inferred from recent observations and theoretical calculations in A = 120–140 region [1–4]. In this paper, we investigate the above features in $^{118-126}$Xe nuclei in a microscopic shell model approach (*i.e.* Deformed Hartree-Fock with angular momentum projection) which has been described in detail by S P Pandya *et al* in their contribution to this proceedings. In the HF approach the shape and its dynamics with other nuclear parameters emerge automatically. The deformed HF intrinsic configuration designated by a K quantum number contains all the relevant information regarding the collective dynamics of the nucleus. Thus angular momentum projection from this configuration reveals the dynamical effects of the observed spectrum. Without going into details of formalism, we directly discuss our results.

2. Deformed Hartree-Fock calculation for $^{118-126}$Xe nuclei

Axially deformed HF calculations are carried out for the valence nucleons in a model space consisting of two major shells both for protons and neutrons lying out side the ^{56}Ni inert

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core. The energies of the spherical single particle states $2p_{3/2}$, $2p_{1/2}$, $1f_{5/2}$, $1g_{9/2}$, $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, $3s_{1/2}$ and $1h_{11/2}$ are taken to be −30.0, −29.0, −29.8, −26.0, 0.8, 0.26, 2.8, 1.3 and 2.5 MeV respectively. We use surface delta interaction of strength 0.85 for *pp, nn* and *pn.* Both the prolate and oblate HF energies and deformations are given in Table 1. Among all ^{120}Xe

Table 1. The intrinsic HF energy (E in MeV), deformations (β) are given for the prolate and oblate solutions for Xe nuclei.

A	E	(β)	E	(β)
	prolate		oblate	
118	−1746.3	.206	−1743.3	−.158
120	−1778.1	.212	−1775.3	−.15
122	−1803.3	209	−1802.2	−.169
124	−1831.5	209	−1830.1	−.169
126	−1859.5	.192	−1857.3	−.15

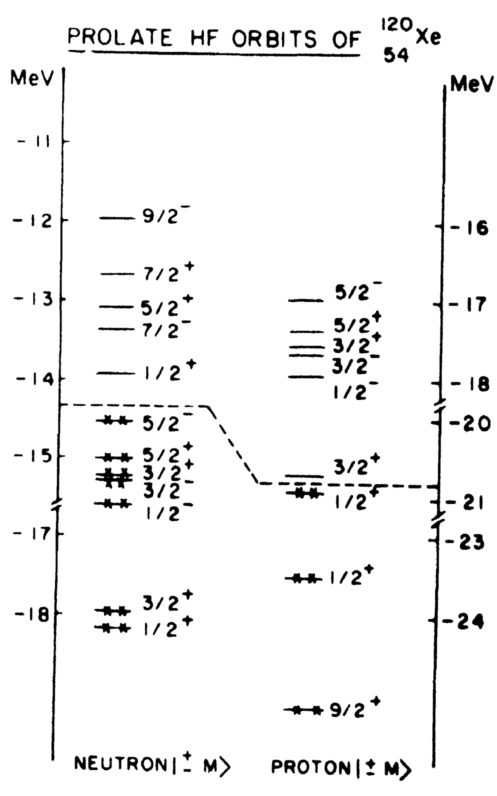

Figure 1. Prolate HF orbits for protons and neutrons near the Fermi surface are shown for ^{120}Xe. Crosses indicate occupied orbits. M (same as k in text) is the magnetic quantum number.

was found to be maximally deformed and is expected to have good band structures. Observations of excited oblate shapes are more probable for higher ($A > 120$) isotones. In the following we describe the band structure of ^{120}Xe, results for other Xe nuclei will be reported elsewhere.

3. Band structures in ^{120}Xe

The HF orbits (see Figure 1) for protons and neutrons show contrasting features. (i) Large gaps are seen around the Fermi surface of protons whereas for the neutrons the single

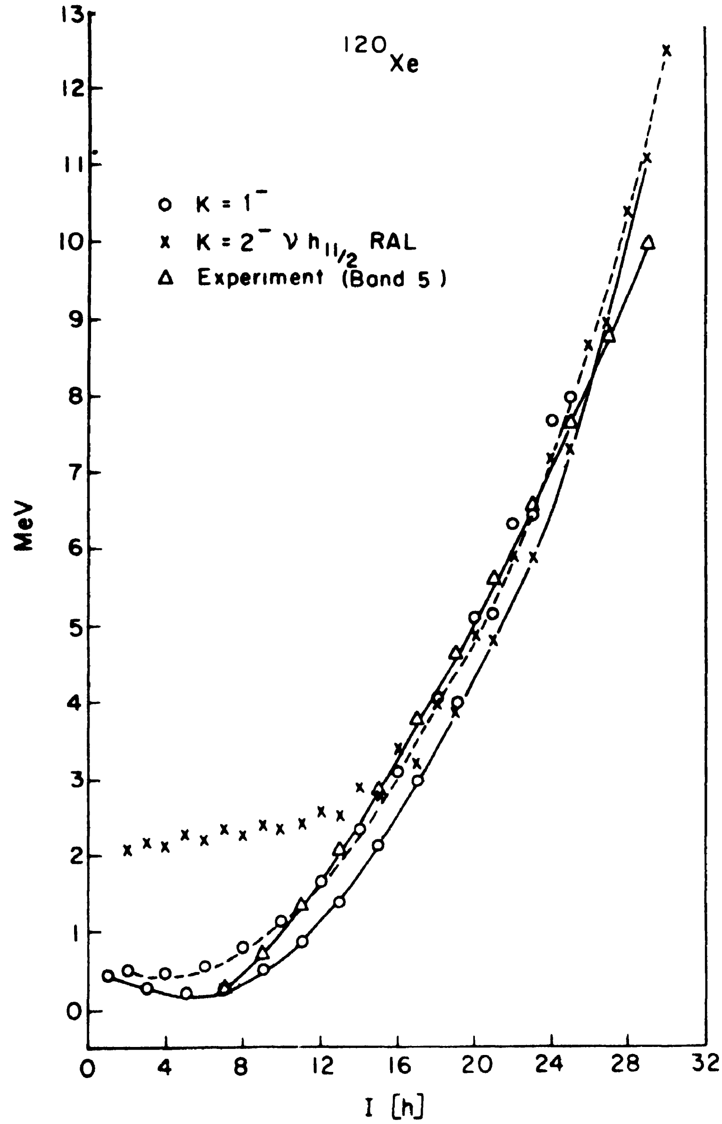

Figure 2a. The lowest energy states obtained by angular momentum projection from the $K = 1^-$, 2^- HF configurations are compared with experiment. The $K = 1^-$ and $K = 2^-$ bands have same intrinsic structure except the fact that the $h_{11/2}$ neutrons in $K = 2^-$ band are arranged in a $k_\pi = 1$ rotation aligned (RAL) configuration. The 7^- state, of the $K = 1^-$ band being lowest in energy, appears as the band head in the experiment. The low spin members of this band lie above 7^- and should be looked for in special experiments.

particle levels are evenly spaced at the Fermi surface. (ii) The neutron Fermi surface is in the mid $h_{11/2}$ shell whereas the low m proton $h_{11/2}$ orbits lie about 2–3 MeV above the Fermi surface. From our HF calculation, we find that all most all the states above the neutron Fermi surface are oblate in nature and hence neutron excitation will lead to reduction in

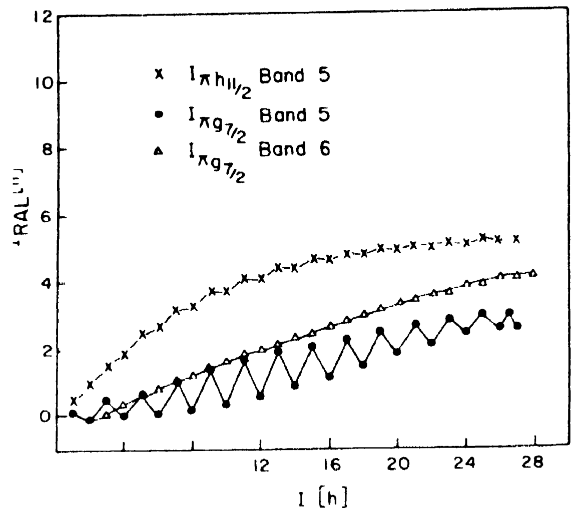

Figure 2b. The staggering in the $h_{11/2}$ and $g_{7/2}$ proton alignment (I_{RAL}) are shown for band 5 and 6 The $h_{11/2}$ and $g_{7/2}$ alignment for the odd I branch is consistently larger than the even I states and hence the odd I sequence is energetically favoured. For band 6 the $g_{7/2}$ alignment smoothly increases with angular momentum and hence no splitting is observed in this band.

collectivity. In fact this is manifested in the observed [1] intensities (of the $E2$ transitions in the ground band) which decreases at the band crossing. The characterstics of all the observed bands are reproduced by angular momentum projection from relevant HF configurations, whose intrinsic structures are listed in Table 2. The agreement of the excitation energies (see Table 2), with experiment in some of the bands could be improved

Table 2. The intrinsic structures of protons and neutrons, deformations, (β), band heads and excitation energies (E^* in MeV) of all the bands observed in ^{120}Xe are given Band 3 could not be identified uniquely.

Band	Experiment [1] Band head	E^*	E^*	Theory Band head	β	k_p	k_n
1	0^+	0 0	0.0	0^+	.212	0^+	0^+
2	2^+	0.876	1.072	1^+	211	$-1/2^+, 3/2^+$	0
3	18^+	6.206					
4	8^+	2.63	2.47	1^+	.19	–do–	$(1/2^+)^2$
5	7^-	2.496	3 655	1^-	.207	$1/2^-, 1/2^+$	
6	5^-	2.073	1.416	3^-	.208		$1/2^+, 5/2^-$

by using modified Nilsson single particle energies [6] which has been used [3] in this region for better reproduction. We find band crossings due to the alignment of $h_{11/2}$ neutrons in the ground band, band 2, 4 and 5 (see Table 2). In band 6 the odd neutron in $h_{11/2}$ blocks the corresponding alignment and related band crossing is not observed. Band crossings arising due to $h_{11/2}$ proton alignment are not considered in the present calculation but nevertheless such crosssings can occur at high spins (> 20). However, we find that alignment of protons in $h_{11/2}$ and $g_{7/2}$ orbits lead to large signature splitting in band 5 (see Figure 2). The even I sequence in this band has been pushed up in energy and has escaped detection. This could be due to weak inter-signature transitions.

4. Conclusions

The important conclusions drawn from our investigation are : (i) Among all the isotopes, ^{120}Xe has larger ground state deformation since the intruder neutron $h_{11/2}$ shell is just half filled. Our calculation reproduces the observed features of the collective bands in ^{120}Xe quite well. (ii) In the particle rotor model it is essential to assume gamma deformation to explain the signature splitting in both the positive and negative parity bands in this region [5], however in our model splitting for both parities comes out naturally with axial symmetry. (iii) Rotation alignment of $g_{7/2}$ protons play an important role in understanding the band structures in this region. (iv) Drastic change of shape was not evident from our calculation though we find relative decrease in prolate collectivity at band crossing. Transition from collective rotational behaviour to single particle like behaviour at relatively low spins has been predicted in ^{122,124}Xe [3,4]. However, shape changes at relatively high spins (> 30) could not be ruled out in ^{120}Xe.

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