Theoretical analysis of structure of even-even $^{130\text{-}136}$Ba Nuclei

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Introduction

Nuclei with mass around $A \approx 130$ have become the focus of both experimental and theoretical efforts in nuclear physics due to a variety of reasons. One of the main features of nuclei in this mass region is that the proton and neutron excitations within the same major shell can compete. Further, the nuclei in this region are found to have a small quadrupole deformation parameter ε_2 and a soft γ-deformation. Some of the widely studied nuclei in this mass region are Xe, Ba and Ce. It has been observed that, in these nuclides, while the proton Fermi level lies in the vicinity of low Ω levels of the $h_{11/2}$ Nilsson subshell, the neutron Fermi level lies in the upper half of the subshell. One can expect the low Ω protons to drive the core towards a more prolate shape, while the neutrons exert an oblate driving force [1].

Since $A \approx 130$ mass region isotopes have interesting properties, their structures have been the subject of many studies. Throughout the last decades, this transitional region has become a laboratory to test the nuclear models. Some of the recent studies were performed in the generalized collective model (GCM) [2], in the pair-truncated shell model [3], and in the relativistic HFB model [4], respectively and a good description of the experimental levels and spectroscopic features of these nuclei have been obtained. In addition, the structure of the wave functions has also been investigated and compared with those of the IBM [4]. In recent years, there have been extensive investigations of the ground-state band (g band) as well as the Stockholm band (S band) in Xe-Ba-Ce nuclei. The interest is mainly due to the presence of an $h_{11/2}$ intruder orbit in this mass region.

The barium isotopes with Z=56 and less than 80 neutrons lying in this transitional region, in particular, serve as rich testing ground for nuclear models. The Ba nuclei have been studied in the past using different models and the observed energy spectra of the low-lying states with E2 transitions have been nicely reproduced.

In the present work, we have used two different techniques, viz. the Projected Shell Model (PSM) and the Variation-after-projection (VAP) technique in conjunction with HFB, to study the even-even $^{130\text{-}136}$Ba nuclei. The nuclear structure properties like yrast spectra, energy splitting, back-bending, etc. have been obtained using these techniques and the results obtained by using these frameworks are also compared with the experimental data as well, in order to test the efficacy of these techniques in describing the observed data.

Outline of Calculational Frameworks

(i) In Projected shell model technique, the total Hamiltonian employed in the present work is

$$\hat{H} = \hat{H}_0 - \frac{1}{2}\chi\sum_{\mu}\hat{Q}_{\mu}\hat{Q}_{\mu} - G_M\hat{P}^{+}\hat{P} - G_Q\sum_{\mu}\hat{P}^{+}_{\mu}\hat{P}_{\mu}$$

where $\hat{H}_0$ is the spherical single-particle Hamiltonian. The second term in the Hamiltonian is the quadrupole- quadrupole interaction and the last two terms are the monopole and quadrupole pairing interactions, respectively. The strength of the quadrupole force χ is adjusted in such a way that the known quadrupole deformation parameter ε_2 is obtained by the usual Hartree-BCS self-consistent procedure. The monopole pairing force constants G_M are adjusted to give the known energy gaps. In the present calculations, the monopole pairing strength is taken as

$$G_M = \left(G_1 \mp G_2\frac{N-Z}{A}\right)\frac{1}{A}(\text{MeV})$$

where + (-) is for neutron (proton) while, in this work, G_1 and G_2 are chosen as 20.20 and 12.12 MeV for all the Ba nuclei. The strength

parameter G_Q for quadrupole pairing is assumed to be proportional to G_M where the proportionality constant is adjusted to reproduce the $h_{11/2}$ crossing at the right place.

(ii) In VAP-HFB method, the Hamiltonian used is of pairing plus multipole-multipole interaction type as

$$H=\sum_{\alpha}\alpha|\in|\alpha>a_{\alpha}^{\dagger}a_{\alpha}+[1/4]\sum_{\alpha\beta\gamma\delta}\alpha\beta|V_A|\gamma\delta>a_{\alpha}^{\dagger}a_{\beta}^{\dagger}a_{\delta}a_{\gamma}$$

where, $\in_\alpha$ are the spherical single–particle energies and $<\alpha\beta|V_A|\gamma\delta>$ is the anti – symmetrized matrix element of an effective interaction. The pairing part can be written as

$$V_P = -(G/4)\sum_{\alpha\beta} S_\alpha S_\beta a_\alpha^\dagger a_{\bar{\alpha}}^\dagger a_{\bar{\beta}} a_\beta$$

where "α" denotes the quantum numbers (nljm).

In Figure 1, the comparison of the observed yrast spectra with the calculated one for ^{130}Ba is presented whereas in Figure 2, back-bending plot for ^{130}Ba is given. The plots of rest of the isotopes and other properties will be presented and discussed during the symposium.

Conclusions

From the results of the calculations, it is found that

- In the HFB plus VAP technique, with the present Hamiltonian used, the maximum spin value of 10^+ was attained, whereas with PSM calculations, the spins upto 30^+ was obtained for all the Ba nuclei.
- The HFB plus VAP technique reproduced the yrast spectra satisfactorily only in the lower spin domain, i.e., for spins upto 6^+only. On the other hand, PSM calculations replicated the experimental data with reasonable accuracy for the entire range of available spin.
- PSM calculations have predicted back-bending in these Ba isotopes approximately at the same spin and near the same angular frequency at which the experimental back-bending was observed. However, with the data obtained by HFB plus VAP technique (limited up to 10^+), no back-bending has been predicted.

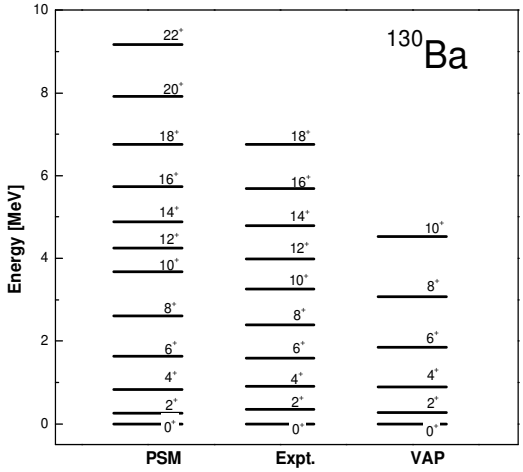

Fig. 1 Yrast Spectra of ^{130}Ba

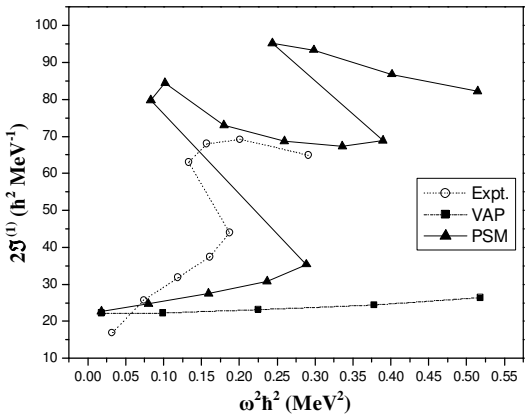

Fig. 2 Backbending in ^{130}Ba

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