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Nuclear structure studies of nuclei near $N = 80$

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Abstract. High-spin states in ^{135,136}Ba, ^{136}La, ^{137}Ce, ^{139}Nd were populated following (HI, χn) reactions and subsequent radiation was studied using in-beam γ-ray spectroscopy methods. Level schemes with new states belonging to the above mentioned nuclei are given.

These nuclei situated near $N = 80$ have been analysed within the framework of the interacting-boson model (IBM), applied to the description of even–even, odd–even and odd–odd nuclei to calculate excitation energies and electromagnetic properties for the above mentioned nuclei.

Keywords. Nuclear structure; interacting boson model.

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1. Introduction

The nuclei situated near $N = 80$ are in a mass region of transitional nuclei, where they show a gradual change from a nearly vibrational structure to one with similarity to a rotational band structure. In the study of nuclei near closed shell configurations, one can expect the interplay between collective degrees of freedom and specific shell-model excitations (two, or three particle clusters) to determine the experimental spectra.

This study as part to a program [1–3] to study the nuclear structure near $N = 80$ reports our results on ^{135,136}Ba, ^{136}La, ^{137}Ce, and ^{139}Nd nuclei. The previous experimental information on ^{135,136}Ba nuclei is very limited, it comes from β-decay, $(n, n\gamma)$ and Coulomb excitation [1,2,4].

2. Experimental procedures and results

The high-spin states in the above mentioned nuclei have been studied using the nuclear reactions induced by ^{9}Be, ^{10,11}B, ^{12}C and ^{16}O ions. The heavy ions were delivered by FN-Tandem accelerator of the NINPE, Bucharest with energies in the range of 30–64 MeV. The experimental information was deduced from γ-ray singles spectra as well as from excitation functions, $\gamma - \gamma(t)$ coincidences and angular distributions. The placement of γ-ray in the level scheme was based on coincidence relationship and relative transition

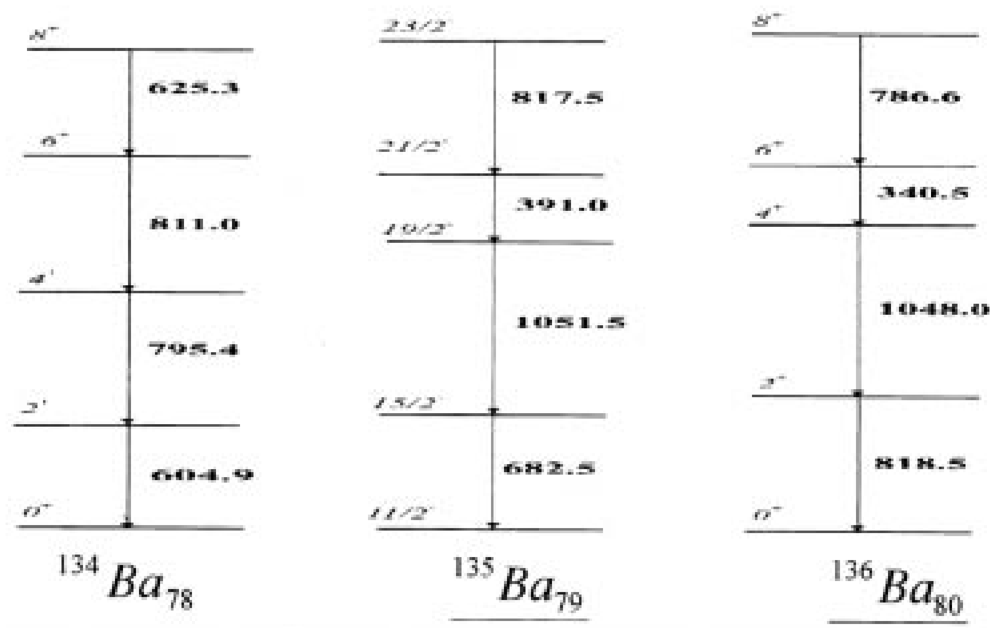

Figure 1. The systematics of the ground-state band in ^{134,135,136}Ba nuclei.

intensities. The spin and parity assignments, the multipole mixing ratios δ were deduced from the angular distribution analysis.

Our results confirmed most of the previously known levels in above-mentioned nuclei [4–8] and level schemes were extended with the spin and the excitation energy, many new levels and bands were observed.

New experimental information is obtained for the ground band in ^{136}Ba which is extended from 6^+ state to 12^+ state and yrast band built on $11/2^-$ in ^{135}Ba (figure 1). A new band $\Delta J = 1$ built on the 204 transition was observed in ^{135}Ba as well as in other $N = 79$ isotones: ^{137}Ce and ^{139}Nd in the present work (figure 2).

3. Discussion

3.1 Level structure of the ^{135,136}Ba *nuclei*

The ground state in ^{136}Ba is very similar to those of $N = 80$ isotones: ^{138}Ce, ^{140}Nd, ^{142}Sm and ^{144}Gd. From figure 1, the band built on $h_{11/2^-}$ has energy spacings very similar with the ground state band in ^{136}Ba and not with ^{134}Ba nucleus, leading to the conclusion that ^{135}Ba nucleus can be interpreted as neutron hole coupled to ^{136}Ba core.

3.2 $\Delta J = 1$ *bands in* $N = 79$ *nuclei:* ^{135}Ba, ^{137}Ce, ^{139}Nd

We observed for the first time a $\Delta J = 1$ band on the $23/2^-$ state in ^{135}Ba, ^{137}Ce, ^{139}Nd $(N = 79)$ and also observed previously in ^{141}Sm, ^{143}Gd and ^{145}Dy [6,8]. The excitation

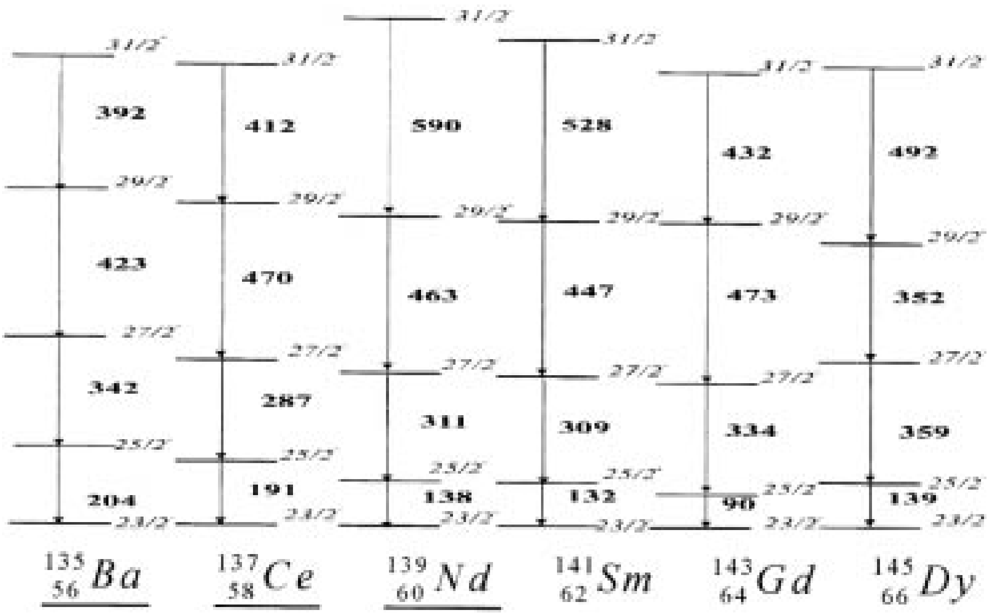

Figure 2. The systematics of the $\Delta J = 1$ band $(\pi h^2_{11/2} \nu h^{-1}_{11/2})$ in the $N = 79$ nuclei.

energy of 23/2$^-$ states in $N = 79$ isotones follows the same trend of the experimentally known $(\pi h_{11/2})^2 10^+$ excitation at $N = 78$ and $N = 80$. These bands probably involve core excitations coupled to the $(\pi h^2_{11/2} \nu h^{-1}_{11/2})$, 1 hole-2 particle states (see figure 2).

3.3 IBM calculations for the ^{135,136}Ba, ^{137}La *and* ^{136}La *nuclei*

In the last decade the interacting boson model (IBM) was extensively applied to the description of even–even nuclei. Its extension to boson–fermion systems, the interacting boson–fermion model (IBFM) [9,12] was applied to odd–even nuclei. Recently, the model was extended to odd–odd nuclei [10,11] and referred to as interacting boson–fermion–fermion model (IBFFM).

The calculation of ^{135}Ba and ^{137}La is performed within the framework of IBFM by the coupling of valence-shell neutron quasiparticles and proton quasiparticles, respectively to the IBM core ^{136}Ba. The core nucleus ^{136}Ba was fitted by using a boson parameterization, which is an interplay between U(5) and O(6) symmetries. The nuclear structure of odd–odd $N = 79$ isotone ^{136}La is described within the framework of IBFFM by coupling of proton and neutron quasiparticles to even–even core ^{136}Ba. The proton orbitals: $1g_{7/2}, 2d_{5/2}$ and $1h_{11/2}$ describe the structure of ^{137}La and the neutron orbitals: $2d_{3/2}, 3s_{1/2}$ and $1h_{11/2}$ describe the structure of ^{135}Ba nucleus. We performed IBFFM calculations for ^{136}La with the residual proton–neutron parameterization [10], $V_\delta = -0.3$ and $V_{\sigma\sigma\delta} = 0.01$. We have calculated the positive and negative parities and compared them with experimental levels in figure 3. The observed level energy spectra are reasonably well described by the

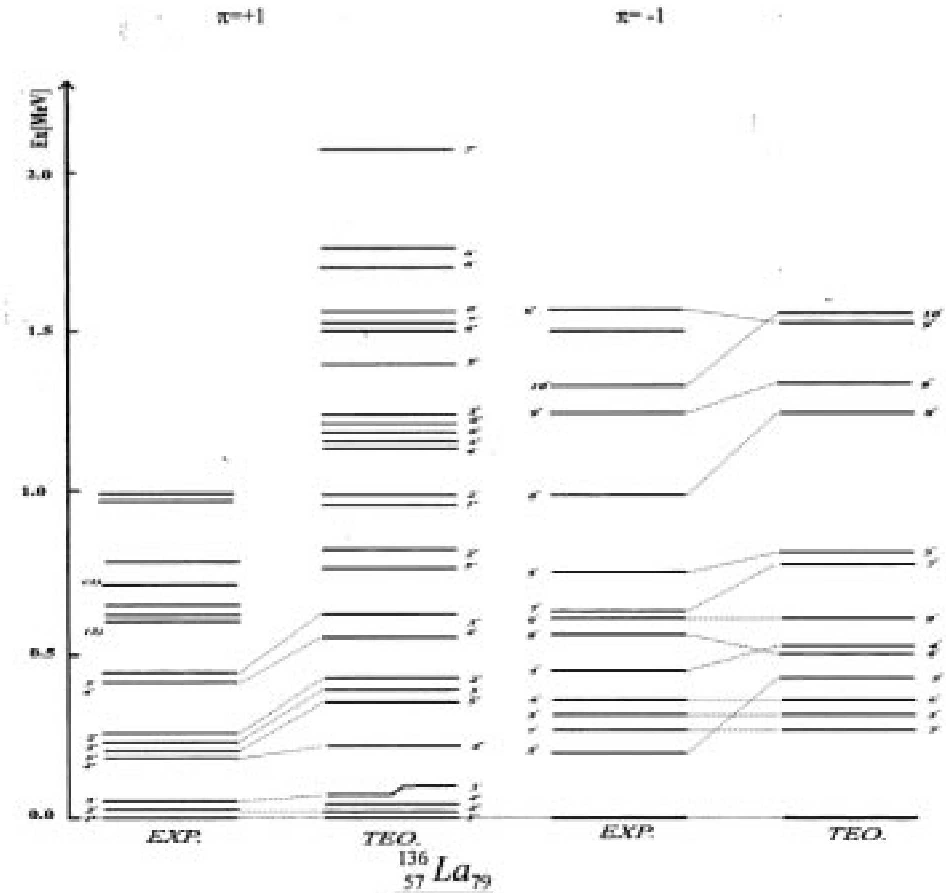

Figure 3. The experimental and the calculated energy spectra for ^{136}La.

IBFFM. The calculated E2 and M1 electromagnetic properties are also in agreement with the observed ones.

4. Conclusions

This paper describes a part of an extensive work to investigate the experimental and theoretical properties of the transitional nuclei, situated near $N = 80$. New bands have been established in all nuclei following (HI, χn) reactions.

The experimental energy level spectra electromagnetic properties were compared with the calculations using the interacting boson model (IBM) with its versions for even–even, odd–even and odd–odd nuclei.

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