HIGH-SPIN LEVEL SYSTEMATICS AND THE EXISTENCE OF TRIAXIAL SHAPES IN ODD-MASS $^{125-133}Ba$

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Abstract

High-spin levels in odd-mass $^{125-133}Ba$ nuclei excited by the reaction $Sn(^{12}C,3n)$ have been studied using in-beam γ-ray spectroscopic methods. Negative-parity states ($h_{11/2}$ system) and positive-parity states ($g_{7/2}$ system) have been identified. The experimental results are in agreement with the predictions of the triaxial core model.

1. Introduction

Decoupled bands in odd-A La isotopes and band structures in odd-A Ce and Nd isotopes have been identified in the transitional region around $A \approx 135$. The interpretation of these results with a particle-plus-rotor model has given evidence of a moderate prolate deformation for these nuclei[1]. More recently, for several isotopes in this region where enough detailed experimental structure was available the triaxial core model has been successfully applied by J. Meyer-ter-Vehn[2].

However, the applicability of the model is more evident in the $A \approx 190$ mass region where the structure of the unique-parity spectra and the existence of low-excited levels are better known, especially in Ir, Au and Tl isotopes.

To obtain more precise experimental information in the $A \approx 130$ mass region and to extend the systematics towards more deficient nuclei, several studies have been undertaken on odd-barium isotopes from A = 133 to A = 125 and are reported here.

In all cases, a negative-parity structure associated with a hole in the $h_{11/2}$ shell has been found. In $^{133}_{56}Ba_{77}$ the basic state of this structure has an $I = j = 11/2$ spin and in the other isotopes with $N \leq 75$, this basis state becomes an $I = (j-1) = 9/2$ state. In odd-barium nuclei with $A \leq 129$, a positive-parity system has been also identified and associated with a hole in the $g_{7/2}$ shell.

These new experimental results are compared with the predictions of the triaxial core model.

2. Experimental procedure

The high-spin states in barium isotopes with A = 133, 131, 129, 127 and 125 have been studied by γ-ray spectroscopy following $(^{12}C,3n)$ reactions on isotopically enriched even-A tin targets. The targets were backed with 25 μm lead.

Excitation functions for the $(^{12}C,xn)$ reactions have been performed at five different bombarding energies between 43 MeV and 57 MeV with beams provided by the Grenoble variable energy cyclotron. The γ-spectra were detected using several Ge(Li) detectors. In-beam and out-of-beam singles spectra were recorded so that both prompt and delayed γ-rays could be identified.

Angular distribution measurements were performed at several angles including 0° and 90° relative to the incident beam. In the case of $^{129,125}Ba$, the experimental A_{44} coefficients have been deduced from γ-spectra taken at seven different angles.

The prompt and delayed γ-γ coincidence events were recorded simultaneously. Half-lives of isomeric levels were deduced from timing against the beam bursts.

3. Results

In this paper, we shall place special emphasis on the favoured band structures strongly fed using the $(^{12}C,3n)$ reaction.

All the levels of these odd-A barium isotopes are not excited in a similar way in these reactions. It seems therefore necessary to emphasize the most important features for each nucleus. In fact, the analysis of the results can be made in three parts, namely, (1) the two heavier members ^{133}Ba (N = 77) and ^{131}Ba (N = 75), (2) the ^{129}Ba nucleus (N = 73), studied in greater details, and (3) the two lighter ones ^{127}Ba (N = 71) and ^{125}Ba (N = 69).

3.1. The ^{133}Ba and ^{131}Ba nuclei

The detailed experimental results concerning excited levels of ^{133}Ba and ^{131}Ba observed in the $(^{12}C,3n)$ reaction are available in a paper already published[3].

The lowest states of the level scheme were previously known from radioactivity studies.

The ground-state spin of ^{133}Ba ($T_{1/2}$ = 10.4 y) is $1/2^+$ and the first excited level at 12.3 KeV ($3/2^+$) is fed by an M4 transition from the $I^\pi = 11/2^-$, $T_{1/2}$ = 38.9 h isomeric state[4] at 288.4 keV. In the $^{124}Sn(^{12}C,3n)^{133}Ba$ reaction, the most intense γ-lines are associated with a band structure based upon this $11/2^-$ state. The perturbed rotational band observed exhibits the same characteristics as one already found[5] in $^{135}_{58}Ce_{77}$ and $^{137}_{60}Nd_{77}$.

The spin assignment of the ground-state of ^{131}Ba ($T_{1/2}$ = 11.5 d) is $1/2^+$. This spin has not been directly measured but is obtained from the $^{131}Ba \rightarrow {}^{131}Cs$ decay and is also in good agreement with the ground-state spin in the neighbouring nuclei ^{129}Ba, ^{133}Ba and ^{129}Xe. The isomeric level at 187.5 keV ($T_{1/2}$ = 14.6 min.) has a $I^\pi = 9/2^-$ spin assignment[6] which is deduced from its de-excitation to the ground-state through a 79 keV (E3) - 108 keV (M1 + E2) cascade corresponding to the $9/2^- \rightarrow 3/2^+ \rightarrow 1/2^+$ spin sequence.

In our in-beam experiment, using intensities, excitation functions, multipolarities and coincidences of the γ-lines, a strong negative-parity band is identified based upon the $9/2^-$ isomeric state. The irregular structure observed is in good agreement with the one already found by (HI,xn) reactions in $^{133}_{58}Ce_{75}$ and $^{135}_{60}Nd_{75}$ nuclei[5].

3.2. The ^{129}Ba nucleus

It was difficult to establish the level scheme of ^{129}Ba presented in fig. 1, because relatively little data were available prior to this investigation using the $^{120}Sn(^{12}C,3n)^{129}Ba$ reaction. Levels had been identified by Griffioen and Sheline in the $^{130}Ba(d,t)^{129}Ba$ reaction[7]. In particular, they have assigned an $1/2^+$ level as the ground-state and have shown that a level at 277 keV, associated with an

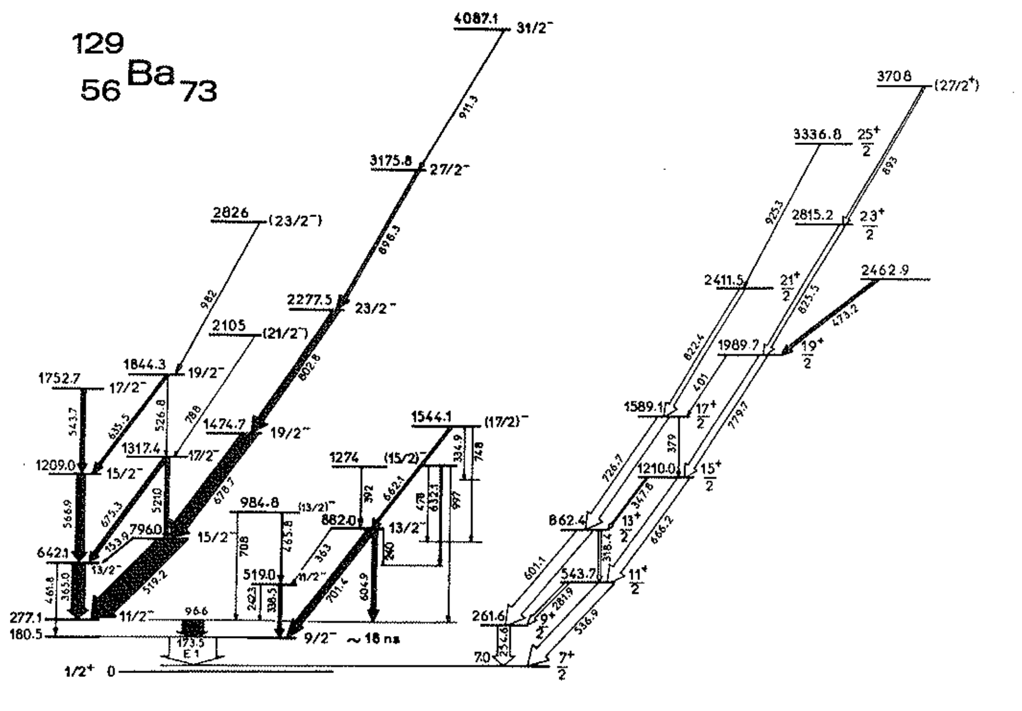

Fig. 1 - High-spin levels of ^{129}Ba excited in the ^{120}Sn(^{12}C,3n)^{129}Ba reaction

angular momentum transfer of $\ell = 5$ could be an $I^\pi = 11/2^-$ state.

A strongly populated cascade of five stretched E2 transitions is found in coincidence with a very strong γ-line having an angular distribution sharply peaked at 90°. Since this cascade is similar to the one already observed in other N = 75 nuclei as ^{135}Nd, ^{133}Ce and ^{131}Ba, an $I^\pi = 9/2^-$ assignment is proposed for the level at 180.5 keV in ^{129}Ba. The yrast cascade is composed of five E2 transitions. By a careful analysis of all the experimental data such as γ-γ coincidences, excitation functions and angular distributions, it was possible to connect several other lines with the cascade mentionned above.

The negative-parity levels of the scheme (fig.1) form a system based on the $h_{11/2}$ hole-neutron orbital which has been separated into two parts. The first part is based upon the $I = j = 11/2$ state and is made of $\Delta I = 1$ bands built on the $11/2^-$ and $15/2^-$ levels at 277.1 and 796.0 keV. Its levels are connected by $\Delta I = 2$ sequences parallel to the yrast cascade. The second part of the $h_{11/2}$ system is built on the $I = (j - 1) = 9/2$ state and has a similar structure. Since these levels lie higher in energy, this part is weakly fed in this heavy-ion induced reaction.

In ^{129}Ba, another set of strongly populated levels is also observed. It consists of two sequences of stretched E2 transitions with spacings similar to those in the yrast cascade. They feed levels connected by weak $\Delta I = 1$ transitions. All γ-transitions in this structure are prompt and there is no connection with the negative-parity system.

The identification of this new set of levels is deduced from the study of the strong and delayed (∿ 18 ns) 173.5 keV γ-ray which deexcites the $9/2^-$ level at 180.5 keV. The experimental angular distribution coefficients indicate that this γ-line is a pure L = 1 transition and linear polarization measurements[8] show that it has an electric character. Therefore, the 7 keV level has an $I = 7/2^+$ assignment since there is no $11/2^+$ available in this region. Our assignment does not contradict the ^{130}Ba(d,t)^{129}Ba pick-up results[7].

3.3. The ^{127}Ba and ^{125}Ba nuclei

Prior to our experiments, there was no information concerning the level structure in these two lighter Ba nuclei. Among the levels excited in (^{12}C,3n) reactions, one observes two band structures which are strongly fed and are similar to those previously described for ^{129}Ba.

As shown in fig. 2, the $h_{11/2}$ system is very similar in both nculei. This is also the case for the $g_{7/2}$ structures presented in fig. 3.

4. Discussion

The odd-mass barium nuclei studied in this work are moderately deformed. Within the framework of the triaxial rotor-plus-particle model they are considered as a triaxial prolate core coupled to an odd nucleon[2]. In the N = 77 case, the odd-neutron corresponds to the first hole in the $h_{11/2}$ shell. For more deficient nuclei, i.e. for lower Fermi energies, a $9/2^-$ state appears as the basic state of the negative-parity structure. This is the case in ^{129}Ba which has been selected as an example to illustrate the following discussion. The systematics have been compared and are treated more fully in a forthcoming paper[9].

4.1. The $h_{11/2}$ system

The arrangement used to classify the levels of ^{129}Ba is able to bring out two subsystems in the $h_{11/2}$ system. In fact this division is provided by the coupling of an odd particle in a pure single j-shell to a triaxial core[2]. This theoretical model predicts that the negative-parity system is broken up into subsystems with basic states of spin $\tilde{\Omega} = j = 11/2$, $\tilde{\Omega} = (j - 1) = 9/2, \ldots$. Each system consists of a set of $\Delta I = 1$ bands respectively based upon $\tilde{K} = \tilde{\Omega}$, $\tilde{K} = \tilde{\Omega} \pm 2$, $\tilde{K} = \tilde{\Omega} \pm 4 \ldots$. The relative position of the subsystems is related to the Fermi energy.

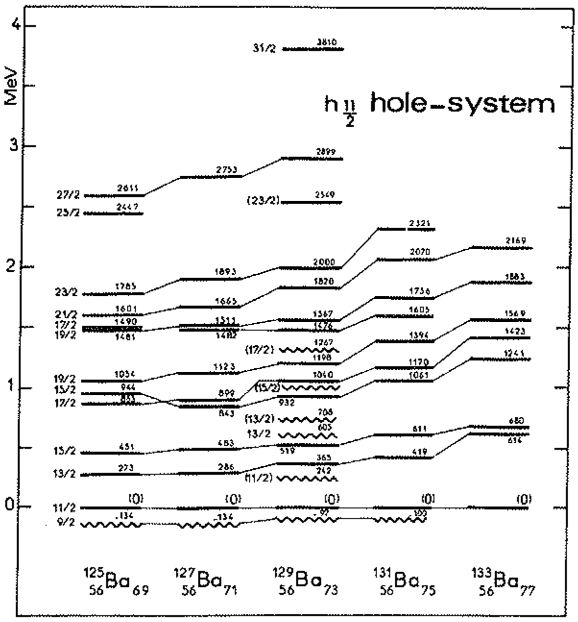

Fig. 2 - Systematics of the $h_{11/2}$ hole-system in odd-A barium nuclei. The wavy levels belong to the $\tilde{\Omega} = 9/2^-$ subsystem.

The two-dimensional level pattern in a subsystem can be qualitatively understood as the rotation of the triaxial core which may occur about different intrinsic axes. If j is the single-particle angular momentum, rotation parallel to j gives rise to $\Delta I = 2$ bands (rotation-alignment) and rotation perpendicular to j gives rise to $\Delta I = 1$ bands (strong coupling).

The experimental structure found in ^{129}Ba cannot be explained for an axially-symmetric core. Consequently the two-dimensional pattern which is especially well developed in the $\tilde{\Omega} = 11/2$ subsystem is good evidence for a triaxial prolate-type shape.

The spectrum calculated with the deformation parameters $\gamma = 21°$ and $\beta = 0.24$ deduced from $^{128,130}Ba$ and without attenuation of the Coriolis interaction reproduces the general trend and the main features of the experimental energies, transition probabilities and $\delta(E2/M1)$ mixing ratios.

4.2. The $g_{7/2}$ system

Although the experimental positive-parity system built upon the $7/2^+$ basic state from the $g_{7/2}$ shell is less complete than that for the $h_{11/2}$ system previously discussed, it has been treated in a similar way. The Fermi energy has been located on the highest orbital of the $g_{7/2}$ shell. Calculations done with the β and γ deformations previously selected for the $h_{11/2}$ system give a better agreement with the observed data than those done using only an axially-symmetric core. Thus the evidence for appearance of the $g_{7/2}$ shell in this mass region is shown here for the first time. Moreover, the observed structure can also be described in the triaxial core model.

4.3. Systematics

The conclusions concerning the levels in ^{129}Ba are considered to be valid for all the nuclei presented in this paper. The systematics of the negative and positive-parity systems are shown in fig. 2 and fig. 3.

The β deformation of the nuclei increases when

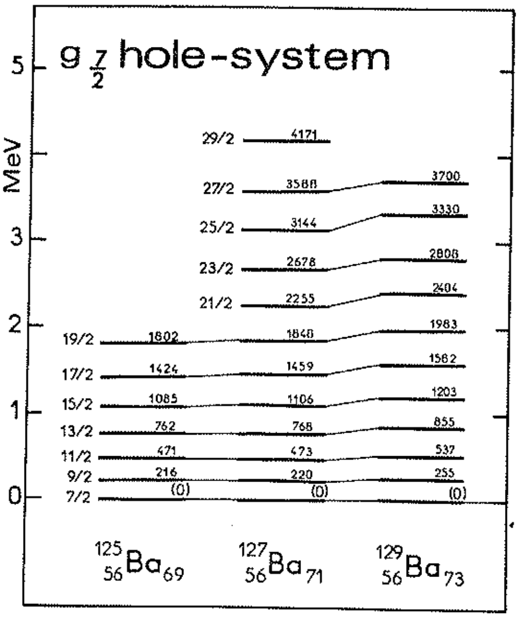

Fig. 3 - Systematics of the $g_{7/2}$ hole-system in odd-A barium nuclei.

the neutron number decreases as shown by the energies of the E2 transitions of the yrast cascade. This is also the trend observed in the level spacings of the ground-state band of the doubly-even barium nuclei. Since the β deformation increases, the Coriolis coupling is reduced as seen from the energies of the $\Delta I = 1$ transitions of the odd-A nuclei. The β deformation tends to be stabilized in the two lighter isotopes since their level structures are very similar.

In the N = 77 case, the Fermi energy is located on the highest orbital of the $h_{11/2}$ shell and, for 75 neutrons, it penetrates inside the $h_{11/2}$ shell. Therefore the first $9/2^-$ level becomes the basic state of the odd-parity system. Afterwards, for more deficient nuclei, this Fermi energy is lowered somewhat till it reaches the highest orbital of the $g_{7/2}$ shell. We must point out that the variations of the position of the Fermi surface are not very sensitive.

The γ deformation also varies with the neutron number. It follows the same trend as in the doubly-even nuclei i.e. it decreases by one or two degrees when going from A to A-2 mass number.

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