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Systematic of Signature Splitting in Ce Nuclei

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ABSTRACT

Signature splitting and signature inversion in rotational bands in ^{132,134,136}Ce nuclei have been studied. These nuclei are interesting candidates for probing the signature of triaxiality. The energy staggering index S(I) has been compared for rotational bands 4 and 5 and found nearly constant in ^{132}Ce. Similarly, S(I) is also found nearly constant as a function of spin in ^{134}Ce for bands 4 and 5. The observed signature splitting in these two nuclei does not support the low K (projection on symmetry axis) value for these bands, on the other hand, a high K value is also not expected for the $\pi h_{(11/2)}$ and $\pi s_{(1/2)}/\ \pi d_{(3/2)}$ configurations at proton number Z=58. Hence, this low and constant signature splitting is only possible due to triaxiality. However, in ^{136}Ce favored and unfavored partner bands (B1 and B2) shows normal signature splitting and indicate an axially symmetric shape for ^{136}Ce.

1. Introduction

Signature splitting is an interesting phenomenon observed in several nuclei and it provides useful information related to the symmetry under the rotation. According to the definition of the signature, the energy levels of a rotational band split into two sequences with $I - j_n - j_p = even$ and $I - j_n - j_p = odd$, where I is the total angular momentum and j_n and j_p are the spin of the odd neutron and proton quasiparticle (QP), respectively. The energy levels with $I - j_n - j_p = even$ spin are found lower in energy compare to the $I - j_n - j_p = odd$ spin states. The first sequence is called the favored signature, and the second one is called as unfavored signature of the band. As a function of spin, the favored and unfavored signatures of a rotational band cross each other in terms of excitation energy, which is known as signature inversion. This is measurable observable, represented by an energy staggering index, S(I) of the band as a function of spin.

The energy staggering index is define as:

$$S(I) = E(I) - E(I-1)/(2I) \quad (1)$$

where, E(I) is the upper energy state and E(I-1) is the lower energy state.

The signature quantum number (α) is associated with symmetry under a rotation of a deformed nucleus around a principal axis by 180°. For the rotation about an axis perpendicular to symmetry axis for an axially deformed nucleus, wave functions remains unchanged under the π rotation and introduces a phase factor $(-1)^{I+K}$ in the energy expression [1-2]. The two sequences are assigned a definite signature quantum number, where I=α *mod 2,* for odd-I and even-I levels different properties of rotational bands can be described in terms of signature quantum number and it is known as a signature-dependent phenomenon. The phenomenon of signature splitting and signature inversion was explained in detail in earlier studies.The magnitude of signature splitting of a rotational band can reveal several interesting pieces of information regarding the structure of a band. Hence, the study of signature splitting and signature inversion has been a subject of current interest for nuclear physicists [3-4].

The signature splitting is generally found very small or nearly zero for a band with the configuration of high K, the projection of the total angular momentum on the nuclear symmetry axis (as shown in figure 1) but it is found significant for bands built on configuration with small K. The signature splitting can be quite substantial for mid to high shell nuclei having high-j valance particles. This can be a result of γ softness in the nucleus. Hence, signature splitting can lead to useful information about the shape and deformation of a nucleus. On the other hand, the angular-momentum projection approach used the interacting

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boson–fermion model suggesting two possible mechanisms for the signature inversion. The first approach suggested a self-inversion and the second one suggested a band crossing between neutron-proton configurations. The favored signature quantum number (α) define as:

$$\alpha = 1/2\left[(-1)^{(Jp-1/2)} + (-1)^{(Jn-1/2)}\right] \quad (2)$$

The favored spin (I) define as:

$$I = [Jp + Jn] mod 2 \quad (3)$$

In the above expression, J_p and J_n are angular momentum quantum numbers of proton and neutron respectively. The signature quantum number (α) is used to determine the order of energy (i.e which signature is favored/unfavored in energy).

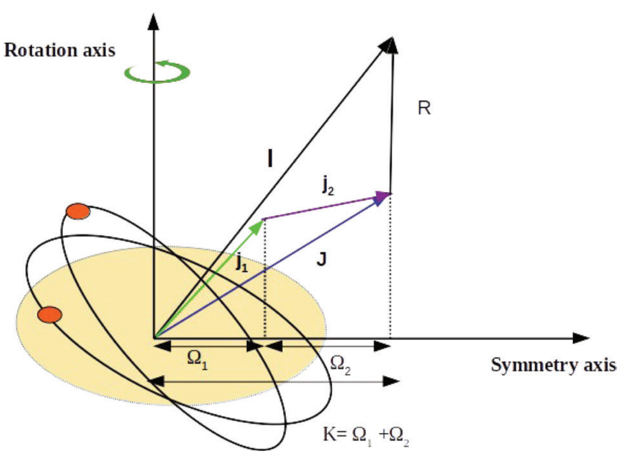

Figure 1: The coupling between two quasi particles leads to the formation of K= ($\Omega_1 + \Omega_2$) band in even- even nuclei.

In even-even and odd–odd nuclei, a rotational band based on two-quasiparticles (TQP) configuration shows various interesting structural phenomena and still a subject of investigation. The band features depend on the mass regions of the nuclei because of the occupancy of the valence nucleons, which are considered to be active orbitals outside of the even–even core. The signature effect in TQP rotational band are still subject of investigation and required more study.

The past experimental studies revealed the significant signature dependence on the K= ($\Omega_1 + \Omega_2$) value in TQP rotational bands [5]. The phenomenon of signature inversion is also considered to be very sensitive to the gamma degree of freedom [6]. The signature splitting and signature inversion were also pridicted as signature of the competition between the coriolis interaction and n–p interaction.

The present work focus on the study of signature splitting of the ΔI = 2 band associated with $\pi h_{11/2}$ and $\pi s_{1/2}$ and $\pi d_{3/2}$ orbitals in even-even **^{132,134,136}Ce** nuclei from the mass A∼140 region. These nuclei are predicted to be γ-soft, hence signature inversion is also expected. The level scheme of the bands of interest are shown in figure 2. These ΔI = 2 bands, show dominated collective in-band E2 transitions, and ΔI = 1 transitions are weak, as shown in figure 2.

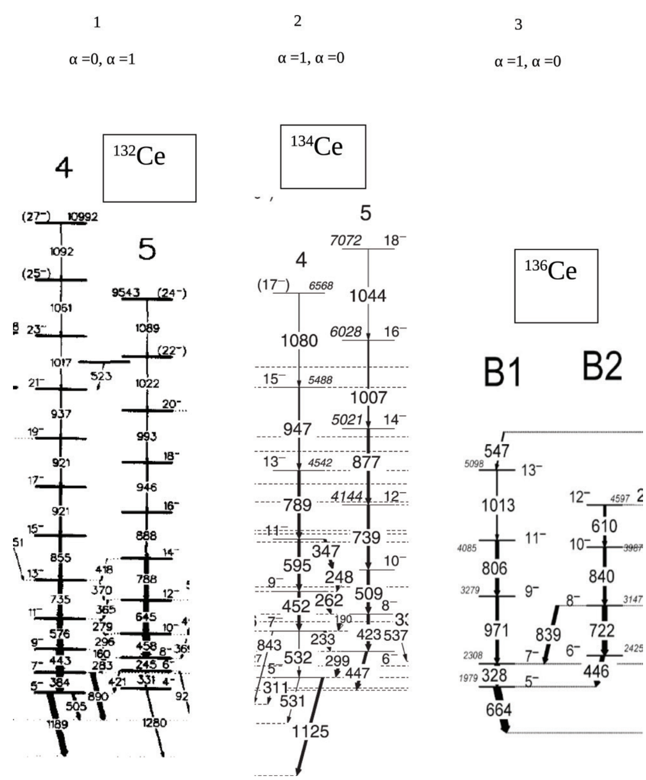

Figure 2: The bands of interests based on $I^\pi = 5$ and $I^\pi = 6$ states in even-even ^{132,134,136}Ce nuclei are shown above. The data is taken from references [7-9].

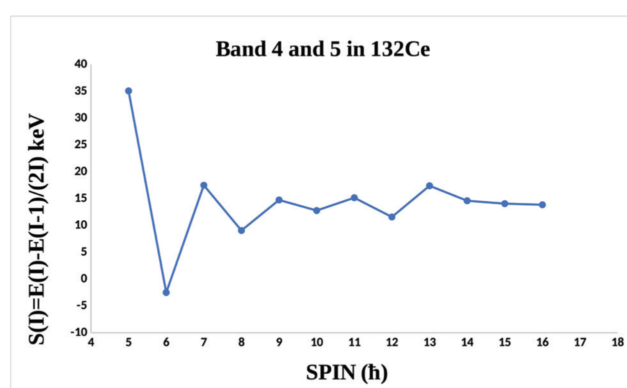

Figure 3(a): Signature splitting of ΔI = 2 bands based on $I^\pi = 5^-$ states and $I^\pi = 6^-$ states in ^{132}Ce.

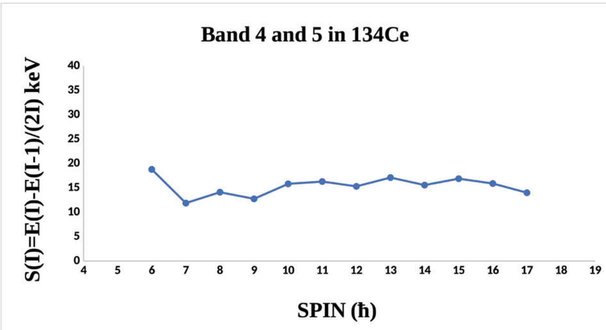

Figure 3(b): Signature splitting of $\Delta I = 2$ bands based on $I^{\pi} = 5^{-}$ states and $I^{\pi} = 6^{-}$ states in ^{134}Ce.

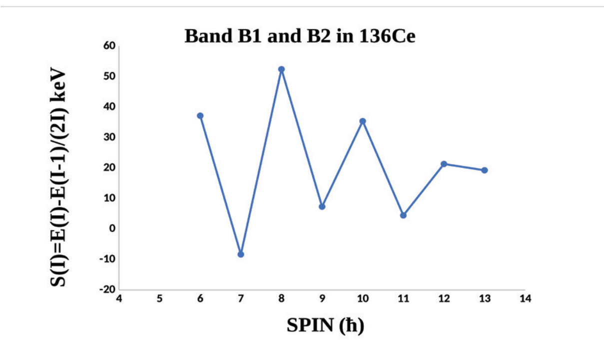

Figure 3(c): Signature splitting of $\Delta I = 2$ bands based on $I^{\pi} = 5^{-}$ states and $I^{\pi} = 6^{-}$ states in ^{136}Ce.

Results and Discussion

In the present investigation, the systematic study of signature splitting of the $\Delta I = 2$ bands viz. band 4 ($I^{\pi} = 5^{-}$ state at 2056 keV), band 5 ($I^{\pi} = 6^{-}$ state at 2477 keV) in ^{132}Ce nucleus [7], band 4 ($I^{\pi} = 5^{-}$ state at 2174 keV), band 5 ($I^{\pi} = 6^{-}$ state at 2473keV) in ^{134}Ce nucleus [8], band B1 ($I^{\pi} =5^{-}$ state at 1979 keV), band B2 ($I^{\pi} = 6^{-}$ state at 2425 keV) in ^{136}Ce nucleus [9] (as shown in figure 1), has been carried out. The energy staggering index S(I) is plotted as function of spin 16$\hbar$ for band 4 and band 5 and found to be nearly constant and its value is relatively very low compartive to the neighbouring nuclei.

For the earlier purposed configuration $\pi h_{11/2}$ and $\pi s_{1/2} / \pi d_{3/2}$ for band 4 and band 5 the associated proton orbitals are expected to have a low K value in Ce nuclei. Hence for the earlier purposed configuration $\pi h_{11/2}$ and $\pi s_{1/2} / \pi d_{3/2}$ can not show low signature splitting. There may be other reasons, such as band mixing or triaxiality may be possible reason for such low and constant signature splitting (figure 3(a)). Similarly, we found low and constant values for energy staggering index S(I) as a function of spin for bands 4 and 5 in ^{134}Ce (figure 3(b)). This also suggests either band mixing or triaxiality in ^{134}Ce. But for bands, B1 and B2 in ^{136}Ce, energy staggering index S(I) is found around 60 keV at lower spin and found to decrease with spin (figure 3(c)). This supports the involvement of low or mid shell K values for proton orbitals in ^{136}Ce. It seems that at neutron number N=78 neutron holes are playing the role to change the shape of ^{136}Ce from triaxial to axial.

Conclusions

The Ce (Z=58) nuclei from the mass A∼130 region have eight valence protons outside the Z=50 closed shell and several neutron holes concerning the closed-shell N=82. The valence neutron holes and protons particles occupy the $0g_{7/2}$, $1d_{5/2}$, $1d_{3/2}$, $0h_{11/2}$, and $2s_{1/2}$ orbitals, we take the full 50∼82 for both neutrons and protons. A study of signature splitting of $\Delta I = 2$ bands in $^{132\text{-}134}$Ce nuclei has been carried out. The energy staggering index S(I) for band 4 and band 5 is found nearly constant. And its value is relatively very low compared to the neighboring nuclei. These bands are associated with configuration $\pi h_{11/2}$ and $\pi s_{1/2} / \pi d_{3/2}$ are expected to have a low K value in Ce nuclei therefore significant energy staggering was expected. Hence, the possible reason for low and constant signature splitting may be band mixing or triaxiality. But for bands, B1 and B2 in ^{136}Ce, energy staggering index S(I) is found around 60 keV and found to decrease with spin. This supports the involvement of low or mid-shell K values for proton orbitals in ^{136}Ce. It seems that at neutron number N=78 neutron holes are playing a role to change the shape of ^{136}Ce from triaxial to axial, where K is the good quantum number.

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Authorship Contribution

A. K. Rana: Has done a literature survey of the interest of the mass region and paper writing.

H. P. Sharma: Supervision and planning of the physics interest in this mass region and validation of the analysis/work.

A. K. Gupta: Help in literature survey, paper writing, and in the figure Potting/Editing.

S.S.T: Help in paper writing and drafting.

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