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Study of Negative Parity Bands in ^{136}Ce

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ABSTRACT

Background: The band structures of Ce(Z=58) nuclei with A~135 were studied extensively with the physics interest such as triaxiality and rotation like-sequence i.e. shears mechanism etc. The level structures of ^{136}Ce, with 58 protons and 78 neutrons, were predicted to arise from the interaction between valence proton particles above the Z = 50 major shell and four neutron holes in the N = 82 major shell. The γ-ray spectroscopy of ^{136}Ce was performed here for experimental investigations.

Purpose: Study the states of two negative parity bands B1 and B2 with band head $I^\pi = 5^-$ and $I^\pi = 6^-$ with level energy 1979 keV and 2425 keV respectively.

Methods: The excited states of ^{136}Ce are populated via the ^{124}Sn(^{16}O, 4n) ^{136}Ce fusion evaporation reaction at E_{beam} = 90 MeV. The emitted γ-rays from the excited nuclei were detected using the Indian National Gamma Array (INGA) spectrometer at IUAC, New Delhi India.

Results: States of two negative parity bands, with band-head I^π = 5- state at 1979 keV and I^π = 6- state at 2425 keV have been studied in the present work. The placement of γ-ray transitions of negative parity band B1 has been changed from the earlier reported work and hence the level energy of this band revised and the systematics study of negative parity bands of isotones with N=78, the ^{136}Ce, ^{134}Ba, ^{138}Nd has been carried out.

Conclusions: The 806.3 keV γ-ray is found altered with the placement of 971 keV γ-ray transition in the earlier reported work and a 1015.2 keV γ-ray transition is placed in the place of the previously reported 1013 keV γ-ray transition above $I^\pi = 11^-$ state in band B1. Previously, B1 and B2 bands were predicted as signature partner bands associated with two-quasiparticle, $\nu[h_{11/2}\otimes s_{1/2}/d_{3/2}]$ configuration. The present work does not support these bands as signature partner bands. Present results are discussed in view of systematics.

1. Introduction

The band structures of nuclei from the A~135 mass region have been in the forefront of nuclear structure research in recent decades and revealed a large variety of interesting phenomena related to triaxial shapes [1], such as the occurrence of chiral partner bands [2-4] and wobbling bands [5-6].

In this mass region, the protons orbitals, $1g_{7/2}$, $2d_{5/2}$, and $1h_{11/2}$, neutron hole orbitals, $1h_{11/2}$, and $1h_{11/2}$, $1g_{7/2}$, $2d_{3/2}$, and $3s_{1/2}$ are lying near the Fermi surface of the nucleus and playing important role in the bands structures and shape evolutions. The negative-parity orbital $h_{11/2}$, is available for both protons and neutrons with low-Ω and high-Ω, hence, playing a significant role in the band structure of the nuclei.

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Because of this, Ce [1-2, and 7] nuclei in this mass region show γ-soft nature. With increasing rotational frequency there is competition between the proton alignment near the bottom of the $h_{11/2}$ subshell and the neutron alignment near the top of the $h_{11/2}$ subshell, which drives the nucleus toward prolate and oblate shape, respectively, known as the deformation driving effect. The resultant of this gives rise to the phenomena of shape coexistence.

The band structures of Ce nuclei with A∼135 were studied extensively with the physics interest of triaxiality [1, 8-10]. The level structures of ^{136}Ce, with 58 protons and 78 neutrons, were predicted to arise from the interaction between valence proton particles above the Z = 50 major shell and four neutron holes in the N = 82 major shell.

The states of ground state band up to $I^{\pi} = 6^{+}$ were established by observing the 552-762.2-900.1 keV sequence of γ-rays transitions by M.Muller et al. [7]. Further, two more sequences of transitions above 5^{-} and 6^{-} in ^{136}Ce were reported by E. S. Paul et al. [11] and proposed as band B1 B2 associated with the $\nu[h_{11/2} \otimes s_{1/2}/d_{3/2}]$ configuration. The measured value of B(E2) is ∼8 w.u. for 762.2 keV transition suggesting low collectivity (ε_2∼0.1) for this band. Also, the presence of irregular 6^{+}, 8^{+} and 10^{+} doublets states indicates non-collective configurations involving $g_{7/2}$ protons or $h_{11/2}$ neutrons for these states. The observation of a long-living isomer at 10^{+} state with the $\nu[h_{11/2}]^2$ configuration suggests the involvement of high j states.

Later, the principal axis cranking (PAC) calculations suggested the B1 and B2 bands as signature partner associated with low-Ω 2-qp configuration $h_{11/2} \otimes s_{1/2}/d_{3/2}$ by S. Lakshmi et al [12]. As one side presence of isomer suggests the involvement of high j originates near the Fermi surface on the other side PAC calculations suggest the presence of low Ω and low j orbitals. In the present work, the experimental investigation was carried out to find the experimental evidence for the support of the interpretations of the signature partner bands.

2. Experimental Details

Excited states of ^{136}Ce were populated via the ^{124}Sn(^{16}O, 4n) ^{136}Ce fusion evaporation reaction at E_{beam} = 90 MeV, using the 15 UD pelletron accelerator facility at the Inter-University Accelerator Centre (IUAC), New Delhi. A target of 1 mg -cm^{-2} was used in the experiment. The γ-rays from the excited nucleus were detected using the Indian National Gamma Array (INGA). In this setup, sixteen clover detectors were used at a different angles, with respect to the beam direction. About 10^{9} two- fold coincident γ-events were recorded by CAMAC-based data acquisition system [13]. Offline data analysis was carried out using the INGASORT [14] and RADWARE [15, 16] computer programmes.

In the INGA setup as the clover detectors are placed at different angle, the number of sets was chosen for the construction of symmetric and asymmetric 4096 x 4096 angle-dependent matrices having energy dispersion of 0.5 keV per channel after gain matching of all the energy spectra. The γ-γ coincidence gates were used for finding the coincidence relationship between γ-rays transitions within the band. For the present experiment, the decay radiations from ^{152}Eu radioactive sources were used for efficiency and energy calibrations.

For the assignment of the multipolarities of γ–ray transitions, two-dimensional angle–dependent asymmetric matrices were used. The ratio of intensities (R_{DCO})of γ–transitions from directionally oriented states was determined as per the following relation:

$$R_{DCO} = \frac{I\gamma_1\left(measured\ at\ \theta 1, gated\ at\ \theta 2\right)}{I\gamma_1\left(measuresd\ at\ \theta 2, gated\ at\ \theta 1\right)} \qquad (1)$$

The R_{DCO} value was used to discriminate the quadrupole and dipole nature of the transitions. In a pure quadrupole /dipole energy gate, the theoretical R_{DCO} values for a stretched quadrupole and for dipole transitions are 1.0 /2.0 and 0.5 /1.0, respectively.

In the present work, the clover detectors were also used as the polarimeter to determine linear polarization asymmetry. Polarization asymmetry analysis is not get completed.

3. Results and Discussion

The proposed partial level scheme of negative parity bands of ^{136}Ce is constructed on the basis of γ-γ coincidence relationships. In this work, the placement of earlier reported transitions of the ground state band (band B4) is verified up to $I^{\pi} = 10^{+}$ state [12]. The placement of γ-rays transitions of negative parity band B1 is verified up to spin $I^{\pi} = 7^{-}$ and found to changed above.

In the present work placement of 971 and 806.3 keV is altered on the basis of intensities of these transitions in the energy gates of 552, 762.2, 328.5 and 664.3 keV transitions. In addition, in place of the 1013 keV transition, we observed a 1015.2 keV transition (fig 1 and 2). There are several other transitions also observed, as marked in the spectra, found belonging to other bands in ^{136}Ce (not a part of the present work).

In the present study the energy levels of band B1 are changed as: $I^{\pi} = 7^{-}$ (2307 keV), $I^{\pi} = 9^{-}$ (3113 keV), $I^{\pi} = 11^{-}$ (4084 keV) and $I^{\pi} = 13^{-}$ (5099 keV). The placement of γ-rays transitions of band B2 is also verified up to spin $I^{\pi} = 12^{-}$ in the present work. The relevant energy gates are shown in figures 1 to 3. The modified partial level scheme including the ground state band and negative parity bands of present interest is shown in figure 4.

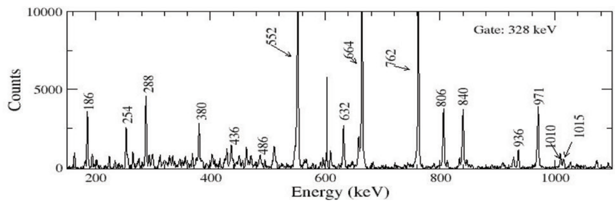

Figure-1: The coincidence energy gate on 328.5 keV, showing the decaying transitions of band B1 and ground state band. Several other transition also observed belonging to other bands in ^{136}Ce.

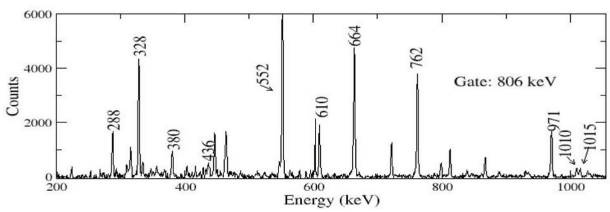

Figure-2: The coincidence energy gate on 806.3 keV, showing the decaying transitions of band B1 and ground state band. Several other transition also observed belonging to other bands in ^{136}Ce.

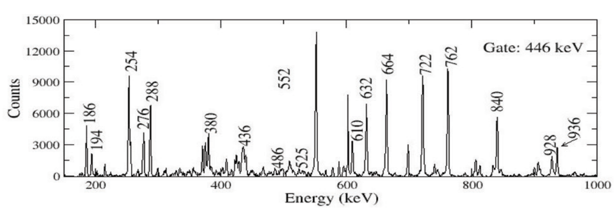

Figure-3: The coincidence energy gate on 446.4 keV, showing the decaying transitions of band B2 and ground state band. Several other transition also observed belonging to other bands in ^{136}Ce.

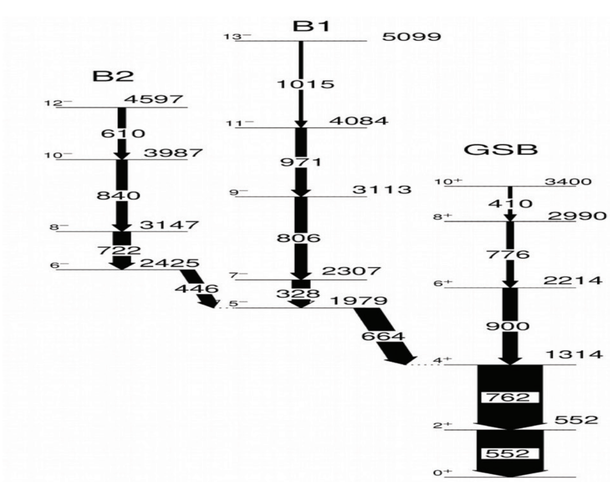

Figure-4: Partial level scheme of ^{136}Ce, constructed from the present work.

In order to understand the behaviour of band B1 in ^{136}Ce nucleus, a comparative study has been carried out with the similar bands reported in the neighbouring ^{134}Ba [17], and ^{138}Nd [18] nuclei having the neutron number N =78. The presently modified energy levels of bands B1 of ^{136}Ce nucleus are found in better agreement with the systematic of the neighbouring nuclei having similar negative parity bands at $I^\pi = 5^-$ state, as shown in figure 5. Further, a comparative study of the level energies of the band B1 in ^{136}Ce with the level energies of band B1 in ^{134}Ba [17] and band N1 in ^{138}Nd [18] suggest a similar configuration for these bands.

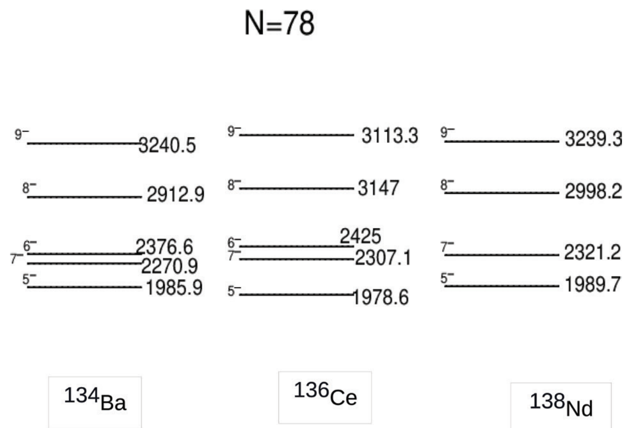

Figure-5: Comparison of present experimental results of ^{136}Ce with the neighboring ^{134}Ba, and ^{138}Nd nuclei having the neutron number N=78 . The data of ^{134}Ba, ^{138}Nd is taken from Refs. [17,18].

However, the band based on $I^\pi = 8^-$ state is not observed in ^{136}Ce and needs further detailed investigation. The band based on $I^\pi = 8^-$ state is reported as the signature partner of the band based on $I^\pi = 5^-$ state at 1986 keV in ^{134}Ba (band C in reference [17]). Similar bands based on $I^\pi = 5^-$ state at 1990 keV (band N1) were found in ^{138}Nd [18] and $I^\pi = 8^-$ state at 2998 keV (band N2 in reference) , but these are not signature partner bands in ^{138}Nd.

From above compersion of systematic of neighbouring nuclei with the same neutron number and also by not observing of the band based on $I^\pi = 8^-$ state in ^{136}Ce, suggest that the band B2, based on $I^\pi = 6^-$ state is not the signature partner of B1 band in ^{136}Ce, as it was suggested in the earlier work [12] . The level energies of the band B2

($I^\pi = 6^-$) in ^{136}Ce do not agree with the level energies of band C ($I^\pi = 8-$) in ^{134}Ba, and the level energies of the band N2 in ^{138}Nd [17,18]. This further indicates that the band B2 has a different configuration and this may not be the signature partner of band B1. Therefore, an experimental investigation was carried out for the signature partner of band B1 in ^{136}Ce.

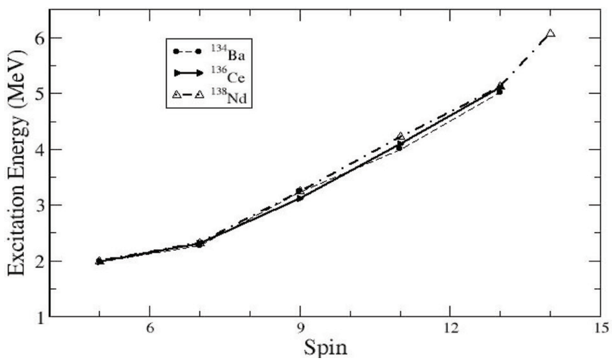

Figure-6a: Comparison of level energies of the band B1 in ^{136}Ce with the level energies of band B in ^{134}Ba, and band N1 in ^{138}Nd [17,18] .

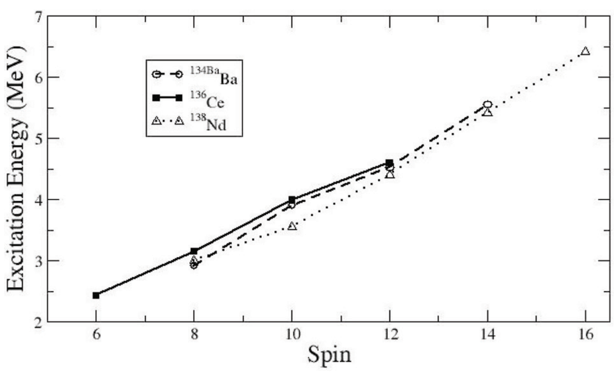

Figure-6b: Comparison of level energies of the band B2 in ^{136}Ce with the level energies of band C in ^{134}Ba, and band N2 in ^{138}Nd [17,18].

4. Summary

Exited states in ^{136}Ce have been investigated using the ^{124}Sn(^{16}O,4n) reaction. The present investigation was carried out using the INGA array. The band structures of ^{136}Ce (Z=58, N=78), with protons above the Z = 50 shell closure and neutrons at the middle of N = 50–82 shell, has special interest due to interaction between proton particle and neutron holes. In the present work, we are mainly reporting the information of negative parity bands B1 and B2.

The placement of previously reported γ-rays transitions of band B1 and the ground state band has been verified [12]. The placement of 806.3 keV γ-ray is found altered with the placement of 971 keV γ-ray transition. A 1015.2 keV γ-ray transition is placed in the place of the previously reported 1013 keV γ-ray transition above $I^\pi = 11^-$ state in band B1. The modified partial level scheme was constructed, and on the basis of the systematic of the bands structures of N=78 isotones (^{134}Ba [17] ,^{136}Ce [12], and ^{138}Nd [18]) the band B2 ($I^\pi = 6^-$) is not found as a signature partner of band B1 in ^{136}Ce.

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Authorship Contribution

A K Gupta: has done the offline analysis of experimental data.
H P Sharma: the planning of the experiment, supervision of the experiments; validation of the data analysis.
S S Tiwary: has contributed to the planning and conduction of experiments, data acquisition, and data analysis.
The rest of the other authors have participated in the experiment and contributed in data collection etc.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

Declaration

It is genuine data and the present work has not been published elsewhere and is not sent elsewhere journal.

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