Superdeformation and shape coexistence in ^{136}Pm

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Introduction

Over the past decade, the study of superdeformation has occupied one of the foremost venues in the nuclear spectroscopy. Since the discovery of first superdeformed (SD) band in ^{152}Dy [1], SD states at high spin have been recognized in the so-called $A \approx 240$, 190, 150, 130, 110, 80, 60, and 40 mass regions. Meticulous theoretical and experimental efforts have been devoted to explore the nature of SD shapes in nuclei [2]. The deformation is always nearly 2:1 axis ratio in the above regions. The shape transition from normal deformed or spherical state into superdeformed shape is one of the very interesting nuclear structure problems.

Significant features of the microscopic structure of superdeformed bands are described by means of occupation of high-*N*, high-*j* intruder orbital, which are brought down in energy close to the Fermi level at large deformation and high rotational frequency. Their excitation energies relative to the Fermi level are found to decrease rapidly with increasing deformation and rotational frequency [3].

In the present work, the detailed studies on superdeformation and shape coexistence in the nucleus ^{136}Pm (A ≈ 130 region) is discussed using rotational energy and dynamical moment of inertia which is compared with the experimental data [4,5] also. Spectacular instances of shape coexistence are obtained and have found clear explanation for the existence of different shapes and of the evolution of the minima. Total energy surfaces (TES) are also generated for better understanding of the underlying mechanism of shape evolution and it offers a fair description of the stability of superdeformed configurations.

Formalism

The logarithmic grand canonical partition function for the hot rotating nuclei is given by [6]

$$\ln Q = \sum_i \left\{ \begin{array}{l} \ln[1 + exp(\alpha_N + \lambda m_i^N - \beta\epsilon_i^N)] \\ + \ln[1 + exp(\alpha_Z + \lambda m_i^Z - \beta\epsilon_i^Z)] \end{array} \right\}. \quad (1)$$

Where the Lagrange multipliers α_Z, α_N, λ and β conserve the number of protons, neutrons, total angular momentum and total energy for a given temperature T = 1/β of the system. The single particle levels for the proton ϵ_i^Z with spin projection m_i^Z and neutrons ϵ_i^N with spin projection m_i^N are generated using the Nilsson Hamiltonian. The number equations for protons, neutrons and the corresponding equations for angular momentum M and energy E are given below:

$$N = \frac{\partial lnQ}{\partial \alpha_N} = \sum_i n_i^N, \quad (2)$$

$$Z = \frac{\partial lnQ}{\partial \alpha_Z} = \sum_i n_i^Z, \quad (3)$$

$$M = \frac{\partial lnQ}{\partial \lambda} = \sum_i m_i^N n_i^N + m_i^Z n_i^Z, \text{and} \quad (4)$$

$$E(M,T) = -\frac{\partial lnQ}{\partial \beta} = \sum_i \epsilon_i^N n_i^N + \epsilon_i^Z n_i^Z. \quad (5)$$

The excitation energy E* of the system

$$E^*(M,T) = E(M,T) - E(0,0). \quad (6)$$

The rotational energy E_{rot} and dynamical moment of inertia $\mathscr{J}^{(2)}$ are given by,

$$E_{rot}(M,T) = E(M,T) - E(0,T), \text{and} \quad (7)$$

$$\mathscr{J}^{(2)} = \hbar^2 \left(\frac{\partial^2 E_{rot}}{\partial M}\right)^{-1}. \quad (8)$$

The free energy F of the rapidly rotating system is

$$F = E - TS \quad (9)$$

where S is entropy of the given system.

Calculations are carried out for the deformation parameter ε = 0.0–0.6 insteps of 0.1 and for shape parameter $\gamma = -180^\circ$ (non-collective oblate shape rotating about the symmetry axis) to $\gamma = -120^\circ$ (collective prolate shape rotating about an axis perpendicular to the symmetry axis).

Results and discussions

Transitional nuclei with $Z > 50$ and $A \approx 130$ have been a subject of much interest as they reveal considerable variations of shapes and deformations with the configuration of valence quasiparticles. Theoretical calculations for this mass region have shown superdeformed shapes stabilized by multiquasiparticle configurations, including one or more deformation-driving $i_{13/2}$ orbitals.

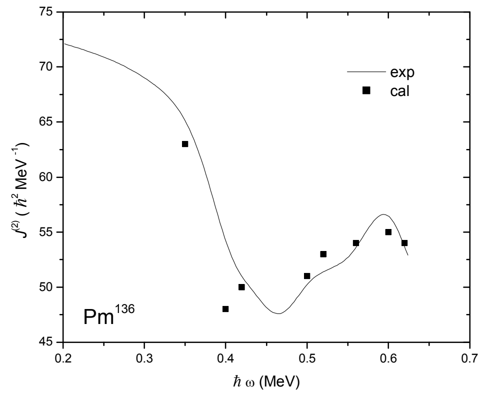

Fig.1 Dynamical moment of inertia as a function of rotational frequency for ^{136}Pm.

Configuration assignment to the band is based on the moment of inertia behavior and it led to the assignment of $\pi h_{11/2} \otimes \nu i_{13/2}$ for superdeformed band in this mass region with the coupling between the lowest $i_{13/2}$ neutron orbital and the favored signature of $h_{11/2}$ proton orbital. Larger $\mathscr{J}^{(2)}$ are observed in the odd–odd nuclei in the 130 region and especially in ^{136}Pm, the $\mathscr{J}^{(2)}$ behavior (Fig. 1) is somewhat irregular due to the orbital interactions and the lower $\mathscr{J}^{(2)}$ moment of inertia here is justified as a blocking effect for the alignment of the first pair of $h_{11/2}$ protons which is known to occur near $\hbar\omega \approx 0.45$ MeV.

Turning to shape coexistence, the ground state yrast band in ^{136}Pm arise from the $\pi g_{7/2}$ and $\pi d_{5/2}$ orbitals and in addition to the yrast band in this nuclei having oblate deformation, it is also evident that another prolate shape coupled with the same single proton orbital (Fig. 2) is strongly competing due to the $i_{13/2}$ neutron. Thus the coexistence of both prolate and oblate shapes are evidenced in ^{136}Pm, as in several other odd-A nuclei in this mass region.

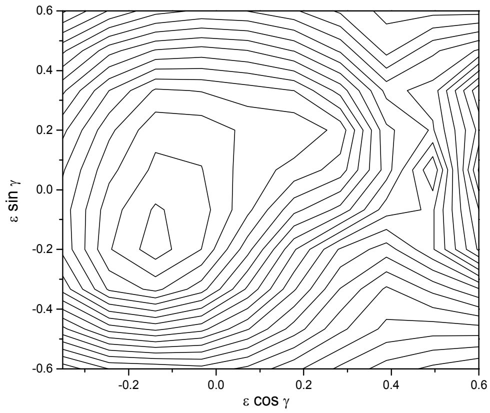

Fig.2 Contour plot of energy in the ε and γ plane for ^{136}Pm.

Acknowledgment

This work is supported by a project (No. 2012/37P/37/BRNS/2017) sanctioned under the Department of Atomic Energy Board of Research in Nuclear Science, India.

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