Shape transition above the yrast line for ^{136}La nuclei

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Introduction

In the last few years considerable experimental effort has been made to investigate rotations and a variety of new phenomena has been observed. Experimental techniques namely heavy ion fusion reactions, coulomb excitation with heavy projectiles and pion capture reactions have made it possible to excite nuclear states with large angular momenta to generate major modifications in the nuclear structure. One such phenomenon which helps to study about the nuclear structure is the yrast line. Yrast line connects the levels of lowest energy to each angular momentum.

With increasing angular momentum the yrast states show a different structure. The reasons are

(a) For low angular momenta, the yrast line follows the ground state rotational band. The rotation is collective, (i.e.,) the rotation is perpendicular to symmetry axis. The coriolis forces act on both spins of a pair and try to align them parallel to the rotational axis which is known as coriolis anti-pairing (CAP) effect.

(b) For higher angular momenta, the coriolis force increases at a certain angular momentum (I_C), the pair breaks and a phase transition occurs. A band is observed which is due to the two aligning particles sitting on the rotation core. This alignment is connected with a rapid increase of the angular momentum (I) as a function of angular velocity probably known as back-bending phenomenon [1].

Excited rotational states for ^{136}La computed for M = (0 to 35)ħ at very low temperature T = 0.5 MeV which ensure the states to be nearly yrast and the effects of rotations are predominant [2]. In the present investigation, constant entropy line, back-bending phenomenon and rotational energy for ^{136}La nuclei are analyzed near the yrast line has been discussed.

Formalism

The nucleus can be described in statistical terms by assigning equal probabilities to all nuclear levels of a given internal energy. Statistical descriptions of many-body quantum systems are usually based on unrestricted grand canonical ensemble averages.

The grand canonical partition function for the hot rotating nuclei is given by [3],

$$\ln Q = \sum_i ln[1+\exp(\alpha_N+\lambda m_i^N-\beta\varepsilon_i^N)] + \sum_i ln[1+\exp(\alpha_Z+\lambda m_i^Z-\beta\varepsilon_i^Z)]$$

where, the lagrangian multipliers α_Z , α_N and λ conserve the number of protons, neutrons and total angular momentum of the system. The average number of particles, total energy and total angular momentum are projected out of the partition function and are given as,

$$\langle N\rangle = \sum_i \{1+exp[-(\alpha_N+\lambda m_i^N-\beta\varepsilon_i^N]\}^{-1}$$

$$\langle Z\rangle = \sum_i \{1+exp[-(\alpha_Z+\lambda m_i^Z-\beta\varepsilon_i^Z]\}^{-1}$$

$$\langle E\rangle = \sum_i \varepsilon_i^N n_i^N + \sum_i \varepsilon_i^Z n_i^Z$$

$$\langle M\rangle = \sum_i m_i^N n_i^N + \sum_i m_i^Z n_i^Z$$

where, n_i^Z and n_i^N are occupational probabilities of the ith shell corresponding to proton and neutron respectively. The entropy (S) is given as,

$$S = \sum_i [n_i^N \ln n_i^N + (1-n_i^N)\ln(1-n_i^N)] + \sum_i [n_i^Z \ln n_i^Z + (1-n_i^Z)\ln(1-n_i^Z)]$$

The excitation energy $E^*(M,T)$ is obtained using the equation,

$$E^*(M,T) = E(M,T) - E_0$$

where, E_0 is the ground energy of the system.
The rotational energy E_{rot} is expressed as,

$$E_{rot} = E(M,T) - E(0,T)$$

Calculations are carried out for cranked Nilsson energy levels for varying the deformation parameter (ε) values in steps of 0.1 from 0.0 to 0.6 and the shape parameter (γ) = -180° (corresponding to non-collective oblate) to -120° (corresponding to collective prolate). Calculations for collective rotations are carried out while the cranking frequency ω is assumed to be zero.

Result and discussion

The excitation energy (E^*) is plotted for the nuclei ^{136}La against the angular momentum (M) for various temperature is shown in fig.1. The constant entropy lines show that for a given temperature as the momentum increases, a systematic change in the shape of the nuclei is observed. A peculiar behavior is observed in ^{136}La nuclei because the critical momentum (M_C) corresponding to the shape transition decreases as the temperature (T) increases. The corresponding deformation parameters are ε = 0.0, γ = -120° (collective prolate) to ε = 0.1, γ = -180° (non – collective oblate). At T = 0.5 MeV, the critical angular momentum (M_C) indicates the shape transition at M = 18ħ [4] and at T = 0.75 MeV, M_C = 16ħ and a similar behavior is observed at T = 1.0 to 1. 5 MeV for M_C = 15ħ.

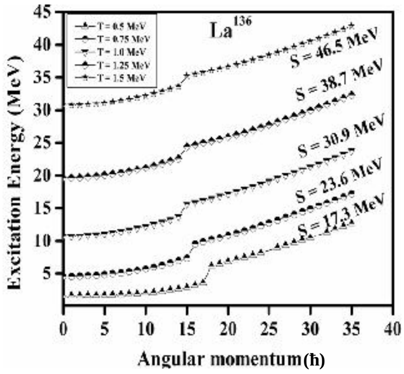

Fig. 1 Constant entropy line

The back-bending phenomenon occurs due to the rapid increase of moment of inertia with rotational frequency towards the rigid value. Rotational frequency plot shows a radical change in the behavior of angular momentum from linearity to stretching and then back to linear. It is an effect due to the crossing of two bands. Two bands have different moment of inertia.

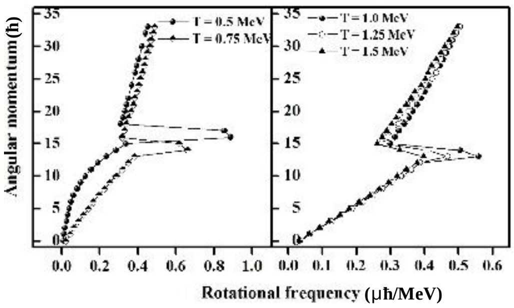

Fig. 2 Back-bending phenomenon

In fig. 2 the back bending effect showing the transition at different critical angular momentum for T = 0.5 (M = 18 ħ) & 0.75 (M = 16 ħ) MeV. Further, the shape transition takes place for the critical angular momentum (15 ħ) for T = 1.0 to 1.5 MeV.

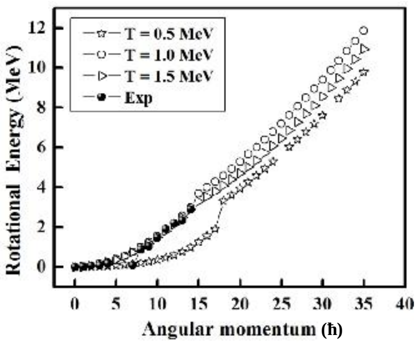

Fig. 3 Rotational Energy

Fig. 3 shows a plot between the rotational energy and angular momentum for the nuclei La^{136} for different temperatures. The dark circles represent the experimental data for ^{136}La [5]. Thus above the yrast line the critical angular momentum corresponds to shape transition shows that it varies with respect to temperature.

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