Triaxial to prolate shape transitions in ^{237}Np

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Introduction

Investigating the structure and dynamics of atomic nuclei is crucial for advancing our understanding of fundamental nuclear physics. A key aspect of this is determining the shape and deformation of nuclei, which significantly impact various nuclear properties like binding energies, excitation spectra, and collective phenomena. One of the most effective tools for probing nuclear deformation is the free energy surface (FES), which maps the total free energy as a function of deformation parameters.

Accurately calculating the FES allows for more precise predictions of resonance behavior. One prominent example of such a phenomenon is the giant dipole resonance (GDR), which plays a key role in the study of nuclear dynamics [1]. The collective oscillation is highly sensitive to the shape and deformation of the nucleus, making the nuclear structure a crucial factor in determining GDR characteristics. The energy, width, and splitting of the GDR peak can vary significantly based on the deformation of the nucleus [2].

In this work, the FES for the nucleus ^{237}Np is calculated at zero angular momentum, with deformation variations analyzed at different temperatures. To evaluate the significance of pairing effects, the calculations are performed both in absence and presence of pairing correlations.

Theoretical Framework

Models based on the microscopic-macroscopic approach are reliable and it is relatively easier to extend these models for deformed hot and rotating nuclei. To calculate the free energy of a deformed nucleus at the finite temperature, we adopt a formalism based on the finite temperature Nilsson-Strutinsky method [3]. The total free energy can be written as

$$F_{tot} = E_{LDM} + \sum_{Z,N} \delta F, \tag{1}$$

where the macroscopic part is calculated with the liquid-drop energy (E_{LDM}) and δF represents the discrete term called the shell correction which can be calculated separately for protons (Z) and neutrons (N). The pairing correlations are handled within the BCS model extended to finite temperature and shell corrections. The pairing is described by the grand canonical ensemble where the particle number fluctuation is allowed by fixing the chemical potential (λ). The corresponding free energy can be determined as

$$F = \langle H_0 \rangle - \lambda N - TS, \tag{2}$$

where H_0 is the nuclear Hamiltonian which is independent of temperature, N is the particle number, and S is the entropy. For the calculations, the realistic mean field of the triaxial Woods-Saxon (WS) potential [4] is utilized, given by

$$V(\vec{r}, \beta) = V_{WS}(\vec{r}, \beta) + V_C(\vec{r}, \beta) + V_{SO}(\vec{r}, \beta), \tag{3}$$

where V_{WS} is the central mean-field potential, V_C is the Coulomb interaction term, and V_{SO} represents the spin-orbit potential. The deformation parameters are given by $\beta = (\beta_2, \beta_4, \gamma)$.

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Results and Discussion

The odd-Z nuclei have a more complex level scheme than the even-even nuclei. Therefore the nucleus ^{237}Np is particularly significant to study FES due to its relevance in understanding nuclear structure and behavior in heavy, deformed nuclei. FES of ^{237}Np without pairing for four different temperatures are shown in FIG. 1. The results indicate a clear evolution in the nucleus equilibrium shape as the temperature increases, transitioning from triaxial at lower temperatures (0.0 MeV) to a prolate shape at higher temperatures (1.2 MeV).

In FIG. 2, the same calculations are done by including the pairing correlations, where its influence on deformation is studied. In lower temperature region, the pairing leads the minima towards higher deformation and less triaxiality. As pairing diminishes with temperature, the FES, with and without pairing correlations become nearly identical, signifying the disappearance of pairing correlations at higher temperatures (1.2 MeV). The thermal excitations at higher temperatures provide evidence for shape transitions from triaxial to prolate, leading to a unified FES.

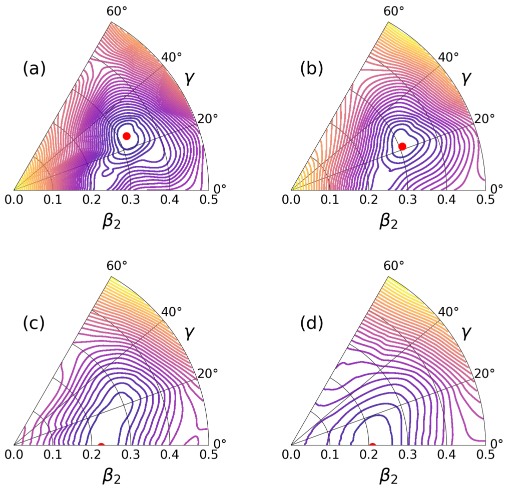

FIG. 1: FES of ^{237}Np without pairing at zero angular momentum for temperatures (a) 0.0 (b) 0.4 (c) 0.8 (d) 1.2 MeV.

This makes ^{237}Np a promising candidate for future GDR studies. Its unique shape evolution under thermal excitation provides rich details for understanding how nuclear deformation and pairing affect GDR properties.

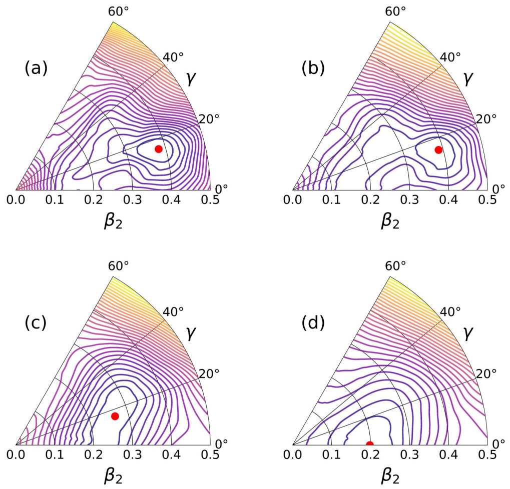

FIG. 2: Same as FIG. 1, but with pairing.

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