N=90 shape phase transition

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Introduction

The even-even N=90 isotones with Z=60-66, present an interesting phenomenon, known as shape phase transition. This phase transition in atomic nuclei is characterized by a sudden change in the shape of the nucleus due to changes in the location of the potential minimum [1]. Nuclei showing such a transition exhibit the critical X(5) symmetry. This X(5) symmetry described by F. Iachello [2] and R.F. Casten [1] in nuclei that are located on the critical point between spherical, U(5) and axially deformed shapes, SU(3). The potential is of the form u(β)+u(γ). The first nucleus to be identified as exhibiting X(5) behavior was ^{152}Sm [1], followed by ^{150}Nd [3], ^{154}Gd and ^{156}Dy [4].

In the present calculations, we have tried to look for the examples of nuclei near the critical-point of the nuclear phase transition based on the potential energy surfaces(PESs). This is done within the Relativistic−Hartree−Bogoliubov (RHB) formalism, supported by the Triaxial Projected Shell Model (TPSM) approach.

Results and Discussion

The energy surface as a function of quadrupole deformation parameters is obtained by solving the RHB equation with constraints on the triaxial mass quadrupole moments. The method of quadratic constraints uses an unrestricted variation of the function

$$\langle \hat{H} \rangle + \sum_{\mu=2} C_{2\mu}(\langle \hat{Q}_{2\mu} \rangle - q_{2\mu})^2$$

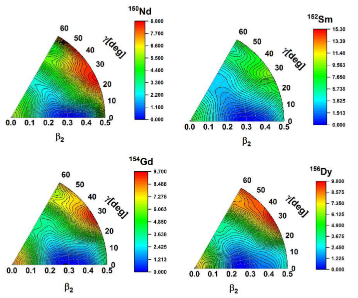

FIG. 1: The potential energy surface of ^{150}Nd, ^{152}Sm,^{154}Gd and ^{156}Dy.

where $\langle \hat{H} \rangle$ is the total energy and $\langle \hat{Q}_{2\mu} \rangle$ denotes the expectation value of the mass quadrupole operators

$$\hat{Q}_{22} = x^2 - y^2$$

$q_{2\mu}$ is the constrained value of the multipole moment and $C_{2\mu}$ the corresponding stiffness constant. Moreover, the quadratic constraint adds an extra force term $\sum_{\mu=2} \lambda_\mu \hat{Q}_{2\mu}$to the system, where $\lambda_\mu = 2C_{2\mu}(\langle \hat{Q}_{2\mu} \rangle - q_{2\mu})$. Such a term is necessary to force the system to a point in deformation space different from the stationary point.

In Fig. 1, there is a flat character in γ−softness towards prolate region in ^{150}Nd, after then it concentrates. The ground state of ^{150}Nd nucleus is axially prolate (0.3,0°). The convergence of circles around the ground state covers β_2 from 0.15 to 0.45, and the softness in $\gamma$is just 10° up to 1.2 MeV of energy. Similar behaviour can be seen in case ^{152}Sm,^{154}Gd and ^{156}Dy. Further, there is an almost gradual increase in energy with the increase in γ for 156 Dy up to $\gamma = 55°$ above which it remains con-

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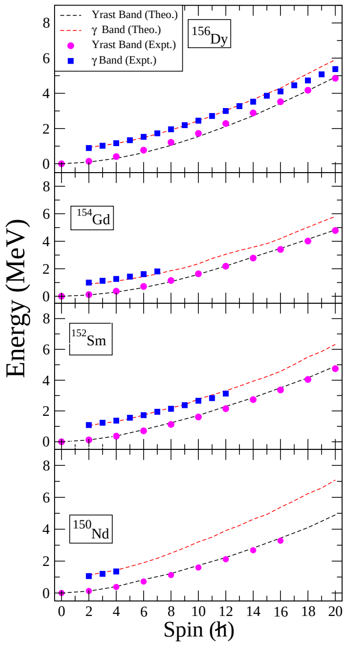

FIG. 2: The yrast band of ^{150}Nd, ^{152}Sm,^{154}Gd and ^{156}Dy.

stant. Based on the above discussion and the other ground state properties (not presented here), The isotopes ^{150}Nd, ^{152}Sm and ^{154}Gd are found to be good candidates while ^{156}Dy is a poor candidates of X(5) critical-point symmetry [5].

Further, multi−quasiparticle triaxial projected shell model (TPSM) approach has been developed and it has been shown to provide a coherent and accurate description of yrast, γ- and $\gamma\gamma$-bands in transitional nuclei. The TPSM calculations proceed in several stages. In the first stage, deformed basis are constructed from the solutions of the triaxially deformed Nilsson potential. The potential is solved for each nucleus with the axial and triaxial deformation parameters, β and γ. The deformations have been earlier calculated for selected nuclei ^{150}Nd, ^{152}Sm, ^{154}Gd and ^{156}Dy, using the microscopic Relativistic−Hartree−Bogoliubov (RHB) approach. In the present TPSM study, we have slightly modified these deformations and is justified as the two models are quite different in nature. The non-axial deformation parameter, γ is, preferably, chosen from the minimum of the potential energy surface (PES) of each nucleus. PES is obtained by evaluating the ground-state TPSM energy for a range of γ values with a fixed value for β. In the second step, the good angular-momentum basis are projected out from the Nilsson + BCS states using the explicit three-dimensional angular-momentum projection operator and in the final stage, these projected basis are used to diagonalize the shell model Hamiltonian consisting of pairing plus quadrupole-quadrupole interaction terms. The TPSM band structures obtained after diagonalization are compared with the known experimental data for the studied even-even nuclei which are presented in Fig. 2. It is evident from Fig. 2 that TPSM reproduces the known experimental data quite well, in particular, the γ-bandhead energy which approximately lies at 1 MeV.

In conclusion, we have investigated ground state deformation and collective motion for neutron-rich even-even ^{150}Nd, ^{152}Sm, ^{154}Gd and ^{156}Dy nuclei. Comparing with experiment, the results are consistent and hence reproduce very well the predicted X(5) nature.

References

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