Spins of Superdeformed Bands in Zr isotopes

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Introduction

The systematic study of the nuclear structure with nucleons provides a better understanding of superdeformation. The collective motion of the nucleons responsible for the change in the nuclear structure from a viberator to a rigid rotor [1] and give rise to the phenomena of superdeformation in terms of SD rotational bands. These SD bands are recognized as the long cascade of transition energies where each energy level is differ by two units of angular momentum. Such a regular pattern of transition energies was first observed in ^{152}Dy nucleus where energy levels assigned to spin values ranging from $24\hbar$ to $60\hbar$. Now more than 300 SD bands observed in $A = 60, 80, 150$ and 190 mass regions [2, 3].

Superdeformation in $A \sim 60$ mass region was experimentally reported in ^{62}Zn [4] where a cascade of six γ-ray transition energies formed a SD band which became least excited at $I \geq 24$ with deformation parameter $\beta = 0.45$. This SD band formed with two $f_{7/2}$ proton holes, play an important role in shape stabilization of SD bands with very large transition energies reaching 3.2 MeV.

In $A \sim 80$ mass region, the SD bands considered to have prolate shape with deformation parameter $\beta = 0.5$. The behaviour of the SD bands in this mass region characterized by their highly collective nature, large dynamic moment of inertia and measured average quadrupole moments.

The first such observation was reported in ^{83}Sr [5] where the superdeformation was elaborated using Doppler shift measurements. The prediction of triaxial SD shapes in first three SD bands of ^{86}Zr and shape coexistence effects in double magic nucleus ^{84}Zr are the attractive points of this mass region. This point is some how contrary to high mass region where triaxial SD shape observed in ^{163,165}Lu.

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Variable Moment of Inertia Formalism

VMI model was purposed by Marriscotti et al., [6] which relates the rotational energy $(\hbar(I(I+1))/2\Im_I)$ with angular momentum (I) of each SD level. The model parameters, band head moment of inertia $(\Im_0)$ and stiffness constant (C) can be calulated for each SD band by fitting gamma transition energies. The VMI equation for SD rotational bands is given by

$$E_I = E_0 + \frac{1}{2\Im_I}\left[I(I+1) - I_0(I_0+1)\right] + \frac{1}{2}\left[C(\Im_{(I)} - \Im_0)^2\right] \quad (1)$$

where E_0 is band head energy and $\Im_I$ is variable moment of inertia of the nucleus for each spin value.

The variable moment of inertia $\Im_I$ can be determined through an equillibrium condition

$$\frac{\partial E(\Im_I)}{\partial \Im_I} = 0 \quad (2)$$

This rises the expression

$$\Im_I = \Im_0\{1 - [I(I+1) - I_0(I_0+1)]/2C\Im_I^3\} \quad (3)$$

This is comparable to the cubic expression

$$\Im_I^3 - \Im_I^2\Im_0 - \{[I(I+1) - I_0(I_0+1)/2C]\} = 0 \quad (4)$$

By combining Eq. (4) with Eq. (1), we get

$$E_I = E_0 + \left[\frac{I(I+1) - I_0(I_0+1)}{2\Im_0}\right] + \left[1 + \frac{I(I+1) - I_0(I_0+1)}{4C\Im_0^3}\right] \quad (5)$$

For SD bands, the transition energy from level $I+2 \rightarrow I$ can be determine as

$$E_\gamma(I+2 \rightarrow I) = E(I) - E(I-2). \qquad (6)$$

Using Eq. (5) and Eq. (6), we get

$$E_\gamma(I+2 \rightarrow I) = \left[\frac{I(I+1)-(I-2)(I-1)}{2\Im_0}\right] + \left[\frac{(I(I+1))^2-((I-2)(I-1))^2}{8C\Im_0^4}\right] \qquad (7)$$

For a SD cascade

$$I_0+2n \rightarrow I_0+2n-2 \rightarrow ...I_0+2 \rightarrow I_0, \qquad (8)$$

the observed transition energies $E_\gamma(I_0+2n)$, $E_\gamma(I_0+2n-2)$, $E_\gamma(I_0+2n-4)$,..., $E_\gamma(I_0+4)$ and $E_\gamma(I_0+2)$ can be least fitted by Eq. (8) with fitting parameters $\Im_0$ and C. This approach is helpful to compare the calculated transition energies with experimental values. The band-head spin at which calculated transition energies well correlate with experimental data, determined as best band head spin (I_0). The band head spin can be determined in terms of the ratio energy over spin (EGOS) as,

$$EGOS = \frac{E_\gamma(I)}{2I} \qquad (keV\hbar^{-1}) \qquad (9)$$

It gives horizontal line when we plotted EGOS against spin. For better understanding of spin assignment, EGOS was calculated and plotted as the function of spin for experimental and VMI equation at three band head spins. The band head spin at which one of the calculated EGOS shows nearly variation with experimental EGOS, assumed to be best band head spin for given SD band.

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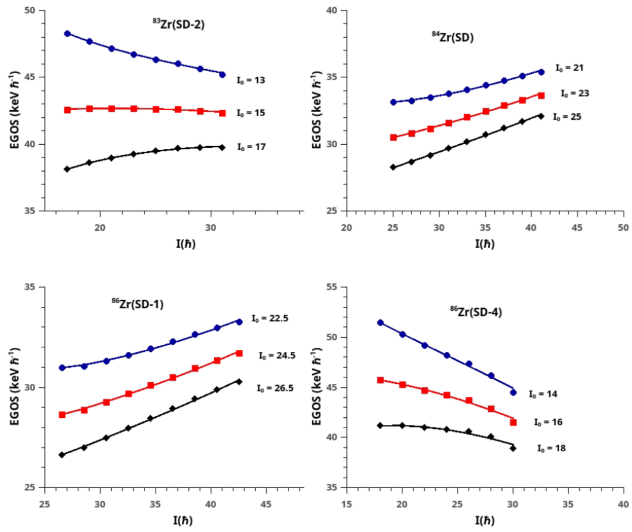

FIG. 1: EGOS versus spin to determine band head spin I_0 for ^{83}Zr(SD-2), ^{84}Zr(SD), ^{86}Zr(SD-1) and ^{86}Zr(SD-4)

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