Spin assignments for band heads in superdeformed Isotopes

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Introduction

Since the discovery of the first superdeformed (SD) band, researchers have identified over 300 such bands across various mass regions, including A = 40, 60, 80, 90, 130, 150, and 190 [1, 2]. Superdeformation was initially observed in ^{62}Zn, marking it as the lightest mass region known for superdeformation at that time and showcasing the highest rotational frequencies. This mass region also includes superdeformed nuclei that are either self-conjugate or nearly self-conjugate and are allowed for the exploration of isospin-sensitive properties in SD nuclei for the first time. The decay-out transitions of the SD band in ^{62}Zn [3] were not clearly established, suggesting a potentially different decay process compared to ^{60}Zn. Subsequent research by Gellanki et al. [4] introduced and connected two additional SD bands. The ^{61}Zn nucleus, having just one neutron beyond the N = 30 SD shell gap, could offer further insights into nuclear properties influenced by variations in valence particles. In present work, we are using the VMI model to examine the properties of SD bands. For nuclei where only one band is known, SD without a number is used.

VMI model

Marriscotti et al. [5] related the potential energy $(J_I - J_0)^2$ and rotational energy $\hbar^2(I(I+1))/2J_I$ for angular momentum (I). Assuming $\hbar = 1$, ground-state energy levels of even-even nuclei ($I_0 = 0$) are expressed as:

$$E_I(J_I) = \frac{1}{2}C(J_I - J_0)^2 + \left[\frac{I(I+1)}{2J_I}\right] \qquad (1)$$

while the band-head energy levels of a rotational band with $I_0 > 0$ are represented as [6]

$$E_I = E_0 + \left[\frac{I(I+1) - I_0(I_0+1)}{2J_I}\right] + \left[\frac{C(J_I - J_0)^2}{2}\right]. \qquad (2)$$

Here, E_0 is the band head energy, and J_I is found using the equilibrium $\frac{\partial E_I(J_I)}{\partial (J_I)} = 0.$, resulting in a cubic equation.

$$J_I^3 - J_I^2 J_0 - \left[\frac{I(I+1) - I_0(I_0+1)}{2C}\right] = 0 \qquad (3)$$

with one real root for finite positive values of J_0 and C. Substituting the value of J_I from Eq.(3) into Eq.(1), we get:

$$E_I = E_0 + \left[\frac{I(I+1) - I_0(I_0+1)}{2J_0}\right] \times \left[1 + \frac{I(I+1) - I_0(I_0+1)}{4CJ_0^3}\right].$$

The ratio EGOS (Energy over spin) is given by

$$EGOS = \frac{E_\gamma(I)}{2I} \qquad (4)$$

where EGOS provides an estimation of accurate band head spin.

A. Study of ΔI = 2 staggering effect

For each band the deviation of the γ-ray energies from a smooth reference ΔE_γ was determined by calculating the fourth derivative of the γ-ray energies E_γ(I) at a given spin I as [7]

$$\Delta E_\gamma(I) = \frac{1}{16}\left[E_\gamma(I-4) - 4E_\gamma(I-2) + 6E_\gamma(I) - 4E_\gamma(I+2) + E_\gamma(I+4)\right].$$

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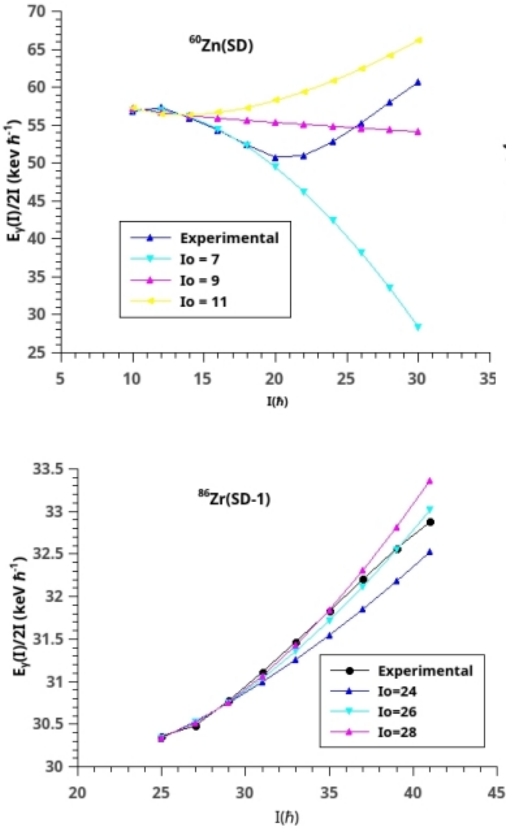

FIG. 1: EGOS versus spin to determine the band head spin for ^{61}Zn(SD) and ^{86}Zr(SD1)

Result and Discussion

To improve understanding of spin assignment, the Experimental Gamma-Ray Overlap Strength (EGOS) was calculated and plotted as a function of spin for both experimental data and the VMI (Variable Moment of Inertia) equation at three different band head spins. The band head spin where the calculated EGOS closely matches the experimental EGOS is assumed to be the best band head spin for the given superdeformed (SD) band (see Fig. 1). The SD bands in the mass regions around 60, 80, and 90 have been observed with γ-ray transition energies up to 3466 keV, 2938 keV, and 2625 keV, respectively. These large differences in γ-ray transition energies may be responsible for the varied behavior of EGOS in different mass regions. For example, in the case of ^{61}Zn(SD), a high-amplitude staggering pattern is observed at low spin values, but this pattern shortens with increasing spin (I) in Fig. 2.

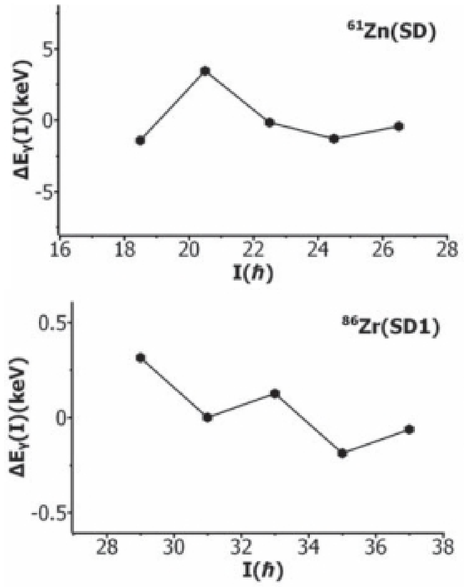

FIG. 2: The experimental ΔE_γ(I) transitions staggering parameter versus spin plot for ^{61}Zn(SD) and ^{86}Zr(SD1).

References

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