Novel Insights into Deformed Nuclear Structures via γ-Band Energy Variations

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Introduction

In this study, the link between rotational momentum (J=6) and transition probability (B(E2)) is analyzed using empirical data to discover a first-order phase change in nuclei, indicating a quantum shift from spherical to deformed nuclear structure. The shift at N~90 is explained, highlighting the groundbreaking investigation of staggering parameters in B(E2). In this article, the term "axially rigid region" refers to the region between the vibrator and the axially symmetric rotor where γ remains rigid, axially aligned with a harmonic oscillator potential, and the lowest in gamma is very close to zero. As part of the Interacting Boson Model (IBA), this region shows the change from the U(5) symmetry to the SU(3) symmetry. This is called a first-order phase transition [2]. The critical point symmetry X(5) has also been linked to this location [3]. In the deformed rare earth region, this work intends to introduce and examine a novel signature by comparing it to an extensive dataset. In the end, we will show that studying energy staggering along an isotopic chain can be a quick and easy way to figure out how nuclear structure has changed over time and maybe even give us clues about how phase transitions happen. Researchers Kumari and Mittal [4] studied the Grodzins product and found a strong association with B(E2). Bindra and Mittal [5] also looked at the ESF and ROTE, both multiplied by B(E2) values, in the context of shape-transitional isotopes and noted several noticeable anomalies in their study. Many nuclear data points have been obtained through experimental study, and theoretical calculations have been revised as a result of contemporary technology developments. Changes in S(J) characteristics with B(E2) and $R_{4/2}$ within the mass range of Gd-W nuclei are the focus of our study. The region between 150 and 180 mass is our main focus since it shows a lot of different features.

Formalism

For γ-bands, we will use the amount [1] to investigate the odd-even staggering:

$$S(J) = \{E(J^+_\gamma) - E[(J-1)^+_\gamma]\} - \{E[(J-1)^+_\gamma] - E[(J-2)^+_\gamma]\} / E(2^+_1) \qquad (1)$$

This amount, normalized to the energy of the ground band's initial excited state, 2^+_1 , quantifies the displacement of the $(J - 1)^+_\gamma$ level with respect to the average energy of its surrounding levels, J^+_γ and $(J - 2)^+_\gamma$. S(J) is highly adaptable to changes in configuration since it takes a confound derivative form. The γ-band levels are shown in Figure 1 together with the associated S(6) values.

Results and Discussion

- **γ-Band Energy Staggering, S(6), in relation with Transition Probability from Gd-W Isotopes**

It is useful to investigate the evolution of a particular characteristic, S(6), in response to structural modifications after examining the variation of S(J) with regard to spin for various nuclear structures. We will now turn our attention to S(6), which is the displacement of the 3^+_γ state with respect to the average energy of its adjacent states, 2^+_γ and 4^+_γ. The 2^+_1 state's energy is used to standardize this quantity. By means of transition probabilities, we examine the changes in S(6) for discrete structures. Figures 1 (left) and 1 (right) show how the staggering of Gd-W isotopes differs. S(6) and B(E2) show comparatively stable and minimal values for the heavier isotopes, $^{152,\ 156}$Gd, ^{154}Dy, and ^{160}Er. But in S(6), every single one of them exhibits a more noticeable distorted pattern. It is a number greater than 82 (N > 82). In fig. 1 (left) at N = 90, $_{64}$Gd shows a sudden kink, followed by $_{66}$Dy, which then exhibits that the heavy rare-earth nuclei display axially symmetric properties, particularly those with neutrons, with a gradually declining trend beyond N ≥ 90. This indicates a shift from vibrator to rotor nuclei, serving as strong evidence for the abrupt start of deformation, consistent with the findings of Caikrili and Casten [6]. And also, we can say that N = 90 is the point where, as shown by the Gd nuclei and the first-order phase transition after N = 92 (at N = 94), Since this study's absolute B(E2) values cover both excitation energies and relative and absolute transition probabilities, they allow for a more thorough analysis of the X(5) model predictions. Also mentioned as potential possibilities for exhibiting the traits of the X(5) critical point symmetry are ^{154}Gd [7] and ^{156}Dy [8].

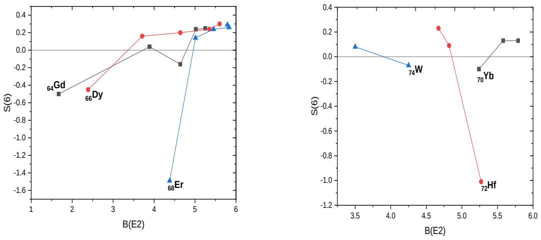

Figure 1: A comparative analysis of S(6)$_{\gamma}$, in relation with (B(E2)) for Gd-W isotopes.

While Fig. 1 (right) comprises isotopes from Yb-W, The findings for Yb-W exhibit notable distinctions compared to the previous calculations that assigned less significance to the more elevated excited levels, and they become more pronounced when examining the Yb-W nuclides. As the value of Z rises and the atomic nuclei become increasingly gamma-soft, the smoother increase in S(6) and that corresponds to a decrease in B(E2) in the case of Hf and W nuclides indicates that the shape transition is less sudden in its manifestation and a transformation from a globular to a distorted configuration occurs abruptly.

Table 1: Transitional isotopes within the rare earth along with Empirical S(6)$_{\gamma}$, values and B(E2) for Gd-W isotopes.

Nuclei	**S(6)**	**B(E2)**
^{152}Gd	-0.5	1.67
^{154}Gd	0.04	3.89
^{156}Gd	-0.16	4.64
^{158}Gd	0.24	5.02
^{160}Gd	0.25	5.25
^{154}Dy	-0.45	2.39
^{156}Dy	0.16	3.71
^{158}Dy	0.20	4.66
^{162}Dy	0.24	5.35
^{164}Dy	0.3	5.60
^{160}Er	-1.49	4.38
^{162}Er	0.14	5.01
^{164}Er	0.24	5.45
^{166}Er	0.26	5.83
^{168}Er	0.29	5.79
^{166}Yb	-0.10	5.24
^{168}Yb	0.13	5.58
^{170}Yb	0.13	5.79
^{176}Hf	-1.01	5.27
^{178}Hf	0.09	4.82
^{180}Hf	0.23	4.67
^{180}W	-0.07	4.25
^{186}W	0.08	3.50

Conclusion

To sum up, the exploration of the development of the S(6) feature in response to structural alterations offers important information about the behaviour of nuclear structures, especially when looking at the staggering patterns in Gd-W isotopes. Heavyer isotopes such as ^{152,156}Gd, ^{154}Dy, and ^{160}Er show stable and minimal values for S(6) and B(E2), with S(6) showing a more prominent distorted pattern when the neutron number goes beyond 82 (N > 82). The rapid kink at N = 90 in ^{64}Gd, and the equivalent behaviour in ^{66}Dy, highlight the onset of deformation and confirm the observations of Caikrili and Casten. This implies a shift from vibrator to rotor nuclei. The abrupt start of deformation, as predicted by the X(5) model, is consistent with this transition, which becomes especially noticeable at approximately N = 90. The analysis also indicates that ^{154}Gd and ^{156}Dy might show the X(5) critical point symmetry. A less abrupt shpe transition towards atomic nuclei that are becoming more gamma-soft is suggested by the opposing results in Yb-W isotopes, where S(6) values climb slowly with a commensurate reduction in B(E2).

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