

Systematic study of Grodzins Product Rule (GPR) with P- Factor

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Introduction

The study of shape phase transition of atomic nuclei has been an ongoing and active issue in study of nuclear structure for over decades. The understanding of p-n interaction for the evolution of structure in atomic nuclei plays a major role. The first discussion regarding the p-n interaction was given by Goldhaber and Shalit [1]. Casten [2] studied the dependence of $E(2_1^+)$ and the ratio $R_{4/2}$ on N_B , N_pN_n and emphasize the importance of p-n interaction for producing the deformation in the nuclear core. Long ago, Grodzins [3] demonstrated a close relationship between the energy of first excited state $E(2_1^+)$ and transition probabilities from the first 2^+ states of even-even nuclei which may be written in the product form

$$E(2_1^+) * B(E2) \uparrow = \text{constant} \frac{Z^2}{A}$$

The constancy in the relationship is maintained while crossing the boundaries between spherical and deformed. Recently, Kumari and Mittal [4] studied the Grodzins Product Rule (GPR) as a function of N_pN_n and showed that structure evolves smoothly. To measure the additional rapid change in the structure, Casten et al. [5] introduced a nucleonic promiscuity factor called P-factor = $2 \frac{N_pN_n}{N_p+N_n}$ (a factor of 2 is introduced here to count in terms of nucleon pairs instead of valence nucleons as in cited reference) where N_pN_n measures the valance p-n interaction (deformation driving) in heavy nuclei are ~ 250 keV and N_p+N_n measures the p-p, n-n pairing interaction (spherical driving) of the order of 1 MeV. The collectivity in the nucleus increases when deformation driving force begins to dominate spherical driving force. If the data are now plotted for Grodzins product versus P-factor = $2 \frac{N_pN_n}{N_p+N_n}$ rather than N_pN_n . This can be viewed as normalized refinement to N_pN_n product.

Method and Calculations

We adopt a grouping based on valance particle and hole pair consideration [6]. Thus the $Z=50-82$, $N=82-126$ into four subspaces or quadrants. The Grodzins product $E(2_1^+) * B(E2) \uparrow$ as a function of nucleonic promiscuity factor $P = 2 \frac{N_pN_n}{N_p+N_n}$ reveals a more detailed understanding of p-n interaction.

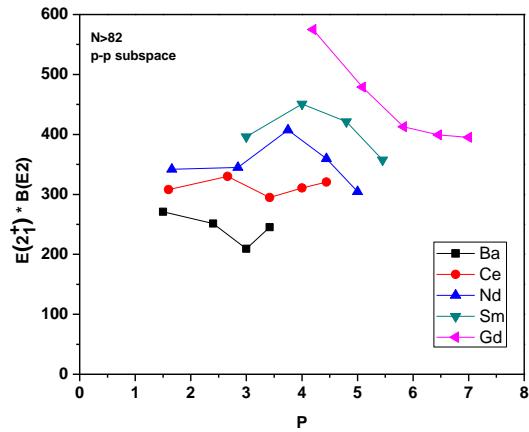


Fig. 1. Plot of $E(2_1^+) * B(E2) \uparrow$ versus P for $N>82$ in Ba- Gd nuclei

Results and Discussion

In quadrant (I) Ba-Gd nuclei ($N>82$), valance particle-particle boson region, the sudden rise in Grodzins product value towards Nd-Gd for $P\sim 4-5$ (see Fig. 1). This is similar to Casten et al. [5]

while analyzing the P-plots with $R_{4/2} = \frac{E(4_1^+)}{E(2_1^+)}$ identifies the transitional class of nuclei. The quadrant (II) Dy-Hf nuclei, ($N<104$) valance hole-particle boson region, is well known SU(3) region. The plot of Grodzins product $E(2_1^+) * B(E2) \uparrow$ versus P yields a smooth decrease in curve for P

values (see Fig. 2). It shows a shape phase transition from SU(3) to U(5) or O(6). Here a P-factor provides a means of predicting some nuclei far from stability. This agrees with the observation of Gupta et al. [7] for observed F-spin multiplets in quadrant (II) and these nuclei are far off from the β - stability line. The quadrant (III) Yb-Hg nuclei ($N>104$), it is well known valance hole-hole boson region recognized for deformed to γ -soft transitions.

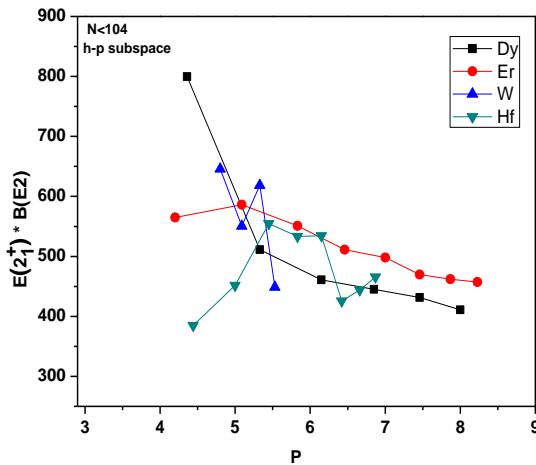


Fig. 2. Plot of $E(2_1^+) * B(E2) \uparrow$ versus P for $N<104$ in Yb-Hg nuclei

The Grodzins product $E(2_1^+) * B(E2) \uparrow$ shows smooth behavior for Hf and W nuclei (see Fig. 3). However, the Grodzins product $E(2_1^+) * B(E2) \uparrow$ does not go well for (Hg, Pt) nuclei with factor P . Casten et al. [8] observed as Z increases beyond 76 the last protons enters strongly upsloping $\frac{11}{2}^-$ [505] and $\frac{7}{2}^-$ [402] orbits. This is energetically unfavorable and the nucleus is driven towards spherical configurations. An interesting implication from this analysis that heavy nuclei with fewer than four valance nucleons of either type can never become deformed (Hg, Pt). This violates the P-factor rule. This, in turn, gives a rule that in all quadrants plotted above, the shape phase transition or deformation occurs for $P = P_{\text{crit}} \sim 4-5$. However the Grodzins product plotted with P

factor is fully consistent with the view point that collectivity increases as a function of $N_p N_n$.

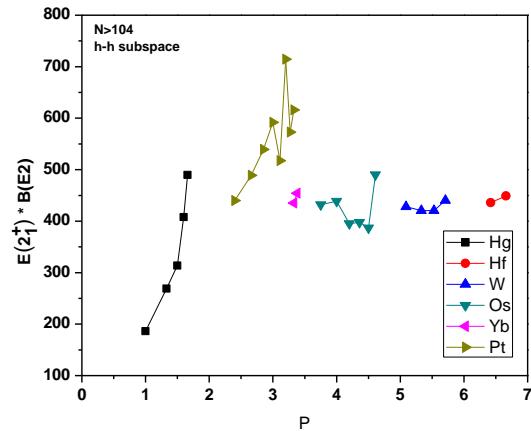


Fig. 3. Plot of $E(2_1^+) * B(E2) \uparrow$ versus P for $N>104$ in Yb-Hg nuclei

Conclusion

We have applied the P formalism to medium and heavy mass nuclei. In all the quadrants studied above, the Grodzins product provides direct dependence of P -factor. The P -factor provides a general and physical meaningful explanation for the development of collectivity. The deformation is seen for $P_{\text{crit}} \sim 5$.

References

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