Systematic study of triaxial deformation in $Ba - Pt$ nuclei

Monica Karday, H. M. Mittal and Rohit Mehra
Department of Physics,
Dr. B. R. Ambedkar National Institute of Technology,
Jalandhar, Punjab, India

Introduction

The interplay between single-particle and collective degrees of freedom governs the shape of atomic nuclei. The atomic nuclei were long believed to be spherical formations. The comprehensive studies of ground and excited nuclear states revealed the non-spherical shapes of various nuclei. The fundamental properties of nuclear shape are expressed through the quadrupole deformation 'β' and asymmetry angle 'γ' [1]. The parameter 'β' is proportional to the intrinsic quadrupole moment and 'γ' decides the type and orientation of shape. The limit $\gamma = 0, \frac{\pi}{3}$ correspond to axially symmetric prolate and oblate shapes, respectively. The intermediate values of γ, viz. $0 < \gamma < \frac{\pi}{3}$ give the triaxial shapes. The theoretical approaches used to investigate the nuclei whose shape deviate from axial symmetry are based on the asymmetric rotor model (ARM) of Davydov and Filippov [2], and γ-unstable rotor model of Wilets and Jean [3]. The ARM is widely useful for nuclei in the transition region between rotational and near harmonic modes of collective excitation. This model pointed out that the spin sequence of the excited states of even-even atomic nuclei, the energy of the states and the electromagnetic transition probabilities between them can be explained adequately if one assumes that in the first approximation the equilibrium shape of the nucleus can be represented by a triaxial ellipsoid. Recently, Kumari and Mittal [4] studied the Grodzins product in the framework of ARM and found that Grodzins product shows a direct dependence on the asymmetry parameter γ. In the present work, the dependence of β and γ parameters on N and N_pN_n , and the correlation of γ with β is studied accumulating the whole mass region of $Ba - Pt$ nuclei. The role of $Z = 64$ subshell in producing smooth systematics has been elucidated.

Theory

The ARM [2] considers the nucleus as rigid triaxial rotor with three unequal axes. The Hamiltonian of ARM is given by

$$H = \frac{\hbar^2}{2} \sum \frac{I_i^2}{\theta_i}, \qquad (1)$$

where I_i are the nuclear angular momentum projections on the axes of a coordinate system connected with the nucleus. We have derived γ using the following equation

$$\gamma = \frac{1}{3} \sin^{-1} \left[\frac{9}{8} \left\{ 1 - \left(\frac{R_\gamma - 1}{R_\gamma + 1} \right)^2 \right\} \right]^{1/2}. \qquad (2)$$

where $R_\gamma = E_{2_2^+}/E_{2_1^+}$. The experimental values for $E_{2_2^+}$ and $E_{2_1^+}$ have been obtained from the National Nuclear Data Center (NNDC) website [5]. The β is evaluated using

$$\beta = \beta_G \left(\frac{9 - \sqrt{81 - 72 \sin^2(3\gamma)}}{4 \sin^2(3\gamma)} \right)^{1/2}, \qquad (3)$$

where $\beta_G^2 \cong (1224/E_{2_1^+} A^{7/3})$.

Results and Discussion

We divide the $Z = 50 - 82$, $N = 82 - 126$ major shell space into four quadrants, based on the consideration of valence particle (p) and hole pairs (h) as suggested by Gupta *et al.* [6]. Casten [7] inferred that nuclear data exhibit a striking similarity when parameterized in terms of N_pN_n. The parameter β is plotted against N and N_pN_n for all quadrants and Fig. 1 displays the plot of β vs. N_pN_n for quadrant-I. Similar plots have also been obtained for γ vs. N and N_pN_n. From the plots of β and γ vs. N_pN_n, we observe that all the data points appear to follow a single smooth curve in quadrants-II and III while in quadrant-I, a greater spread is observed below $N = 90$ for both β vs. N_pN_n and γ vs. N_pN_n. We attempted to replot the quadrant-I by considering the $Z = 64$ shell gap, defining the proton shell as $Z = 50 - 64$ for $N < 90$ whereas for $N \geq 90$ the protons are still considered to fill $Z = 50 - 82$ shell. This $Z = 64$ subshell gap is, however, small and disappears at large deformation. The result of taking such subshell changes into account is clearly visible in Fig. 2 which is much smoother than that obtained previously without considering the $Z = 64$ subshell gap (see Fig. 1) and illustrates the importance of taking these subshell changes into account. Consequently, a remarkable similarity is displayed in all the quadrants, and β and γ are found to correlate extremely well with N_pN_n. The asymmetry parameter γ has also been plotted against β and a linear correlation between β and γ is clearly evident. In all the quadrants, the γ approaches the triaxial value only when the β deformation is small and the strongly deformed nuclei are rather axially symmetric. Nevertheless, β and γ are strongly correlated in all the quadrants.

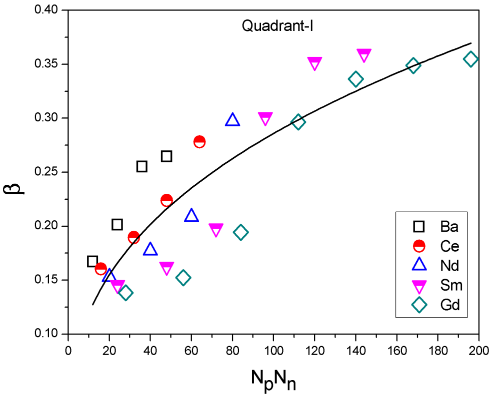

FIG. 1: The plot of β vs. N_pN_n for quadrant-I.

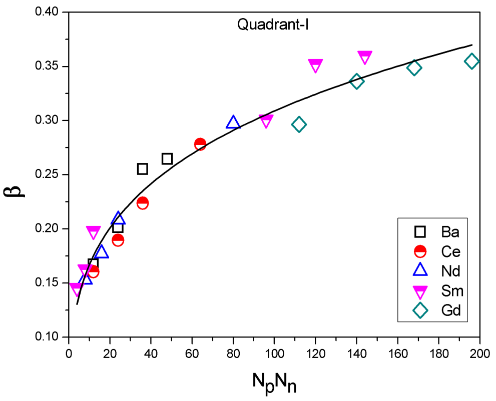

FIG. 2: The plot of β vs. N_pN_n for quadrant-I considering $Z = 64$ shell gap.

Conclusion

The parameters β and γ are found to vary smoothly with N and N_pN_n. The deviations from smooth systematics have been well accounted for by considering the crucial role of $Z = 64$ subshell. The present analysis lead to a general argument that the rigid triaxiality is a feature of moderately deformed nuclei.

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