Role of asymmetry in breakdown in N_pN_n scheme

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The rigid triaxial rotor model (RTRM) considers the nucleus as a rigid rotor with rigid triaxial asymmetry γ. For a fixed value of deformation parameter (β) violation of axial symmetry of the nucleus leads to an increase of energy of the levels belonging to the axial nucleus in the Davydov Filippov model [1]. The increase of level energy is corresponds to the decrease of effective moment of inertia of the nucleus. For the first excited state of spin 2 the effective moment of inertia is determined from the relation –

$$E2^+_{1,2} = \left(\frac{6\hbar^2}{2\theta_0}\right) \frac{a-(-1)2\sqrt{81-72\sin^2 3\gamma}}{4\sin^2 3\gamma} \quad (1)$$

Where $\sigma_{1,2}$ = 0, 1. The reduced E2 transition rate from the $2^+_{1,2}$ states to the ground state can be expressed as –

$$B(E2; 2_{1,2} \to 0^+_1) = \frac{1}{2}\left(\frac{e^2 {Q_0}^2}{16\pi}\right)\left[1 + (-1)^{\sigma_{1,2}} \frac{3-2\sin^2 3\gamma}{\sqrt{9-8\sin^2 3\gamma}}\right] \quad (2)$$

Where $Q_0 = \frac{3ZR^2\beta}{\sqrt{5\pi}}$

And the value of $B(E2; 2_2 \to 0^+_1)$ is given by –

$$B(E2; 2_2 \to 0^+_1) = \frac{10}{7}\left(\frac{e^2 {Q_0}^2}{16\pi}\right)\left[\frac{\sin^2 3\gamma}{9-8\sin^2 3\gamma}\right] \quad (3)$$

In the present work, we evaluate the value of γ of even – even Hf nuclei from equations 1, 2 and 3. The asymmetry parameter γ are calculated from the energy ratio $\left(\frac{E2^+_2}{E2^+_1}\right)$ are written as γ_e while calculated from B (E2) branching ratio $\left[\frac{B(E2;2_2\to 2^+_1)}{B(E2;2_2\to 0^+_1)}\right]$ are written as γ_b. We keep in mind that although the Hf nuclei are known to be γ – soft and RTRM embodies a nuclear shape with rigid triaxiality, the expectation or rms values of γ should be valid. In the N_pN_n scheme the interactive forces inside the nucleus are said to be proportional to the product N_pN_n. The product is proportional to the B (E2) transition value $B(E2; 2_1 \to 0^+_1)$ and to the level energy $E2^+_1$.

In table – I, we observe that in $^{164-170}$Hf nuclei the values of N_pN_n increase so the B (E2) values, while $E2^+_1$ values decrease. Thus N_pN_n scheme is followed. For $^{164-168}$Hf nuclei, the values of γ calculated in different ways from energy ratios (γ_e) and E2 transition ratio (γ_b) are almost equal, but in ^{170}Hf the γ values are quite different (γ_e = 12.8, γ_b= 25.7). Therefore, the internal consistency of RTRM is found to be disturbed. In ^{172}Hf nucleus a sudden breakdown in N_pN_n scheme appears. The B (E2) value decreases instead of increasing with the increase of N_pN_n. At the same time the value of γ_b is also reduced to 18^0 from 25.6^0 thus, lowering the gap between the γ_e and γ_b. In the next nucleus ^{174}Hf the difference between γ_e and γ_b vanishes and B (E2) starts increasing again with the increase in N_pN_n. It continues further in ^{176}Hf nucleus.

In the above observations it is clear that the erratic value in γ has some role in starting the breakdown in N_pN_n scheme. The erratic value of γ challenges the internal consistency of rigid triaxial rotor model and also bring breakdown in N_pN_n scheme. The above systematic repeated again in N_pN_n scheme where the difference between γ_e and γ_b is large in ^{180}Hf and the breakdown is followed from ^{182}Hf.

Table – I

Nucl.	N_pN_n	$E2_1^+$	B(E2) ↑	γ_e	γ_b
^{164}Hf	100	211.0	2.14(18)	19.7	21.8
^{166}Hf	120	158.5	3.50(20)	17.2	14.5
^{168}Hf	140	124.0	4.30(23)	14.8	17.2
^{170}Hf	160	100.8	5.30(12)	12.8	25.7
^{172}Hf	180	95.2	4.47(33)	12.5	18.0
^{174}Hf	200	90.9	4.88(31)	12.6	12.9
^{176}Hf	220	88.4	5.27(10)	10.7	14.9
^{178}Hf	200	93.2	4.82(6)	11.2	-
^{180}Hf	180	93.3	4.67(12)	11.2	27.0
^{182}Hf	160	97.8	5.09*	13.6	<13.7

*The B (E2) value for ^{182}Hf is evaluated employing Grodzins [4] relation

$$\frac{A.E2_1^+.B(E2;2_2\rightarrow 0_1^+)}{Z^2} = (2.5+1)\times 10^{-3} \quad MeV.e^2b^2$$

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