Rigid rotational structure of g, β and γ bands in heavy mass nuclei

*K. K. Gupta[1], Chhail Bihari[2], Y. Singh[3], M. Singh[4] and A. K. Varshney[5]

1. *Govt. College, Dhaliara (HP)-177103, India*
2. *Bon Maharaj Engg. College, Vrindavan, Mathura (UP)-281121, India*
3. *Govt. College, Dharmsala (HP), India*
4. Department of Physics, NIET, Gr. Noida-201306 (U.P.), INDIA
5. *R.G.M. Govt. P.G. College, Jogindar Nagar (HP), India.*

* *E-mail- gupta.phys@rediffmail.com*

According to Bohr – Mottelson unified collective model the low-lying levels of even Z even N nuclei in mass region A ~ 220-250 away from closed shells are expected to develop collective characteristics. The lowest levels are grouped into three K – bands. The lowest one based on the ground state forms the ground state rotational band (K = 0_1). Another band based on the axially symmetric vibrations of the nuclear core with K = 0_2 is called the β – vibrational band. The third one based on axially asymmetric vibrations of the nuclear core with K = 2 projection on the symmetry axis is called γ – vibrational band. In a rigid rotor model the rotation of the rigid asymmetric nucleus not only yields yrast (ground state rotational) band but also 2+, 3+, 4+, 5+,……….levels (anomalous rotational band or γ – band) as the value of the asymmetry parameter γ increases. Toki and Faessler have commented that the γ – band is one rotational band when the asymmetry parameter is small ($0^0 < \gamma < 15^0$) at larger γ – deformation one should take R = 2_2^+, 4_2^+, $6_2^+ \ldots$ as one band and R = 3_1^+, 5_1^+, $7_1^+ \ldots$as another band. This observation is based on the study of the quadrupole moments and the B(E2) values as a function of the γ – deformations [1]. The physical reason is attributed to a repulsive force (between even spin members of ground band and even spin members of γ – band) that gives up turn to $E4_2^+, E6_2^+, E8_2^+$ at $\gamma > 15^0$. The examples of collective excitations resulting in both oscillations and rotations are well established in the form of γ – soft by Wilets & Jean and γ – rigid by Davydov & Filippov. The energy gaps $\Delta E_1 = E3_1^+ - (E2_1^+ + E2_2^+)$ and $\Delta E_2 = E3_1^+ - (2E2_1^+ + E4_1^+)$ Play an important role in distinguishing the rotational and oscillatory structure of nucleus. Viz.

$\Delta E_2 >> \Delta E_1 \approx 0$ (In rotational nuclei)

$\Delta E_1 >> \Delta E_2 \approx 0$ (In Oscillatory nuclei)

The energy ratio $R\left(\frac{4}{2}\right) = \frac{E4_1^+}{E2_1^+}$ is a good measure of the deformation of a nucleus with the variation in N and Z it can assume value of 2.0 for the spherical vibrator to 3.33 for the deformed rotor in the ground state band. For a collective rotations based on the intrinsic axial vibration the value of R (4/2) is expected to be the same for β – band (K = 0_2) and ground state band (K = 0_1).

In the present work we undertook some heavy mass even nuclei including Th, U and Pu belonging to mass region A ~ 220 – 250 and treat the low – lying g, β and γ bands in the Soft Rotor Formula (SRF) which we used earlier for studying γ – band in medium mass nuclei [2]. We consider that the rotation is one of the specific collective motions in finite body systems and why cannot rotation with slightly different moment of inertia about different axes of asymmetric atomic nucleus generate the low – lying energy levels. A modified SRF has been especially meant for β and γ bands [3] used in present work. According to which

$$E_I = E_K + \frac{I(I+1)}{2\theta_0(1+\sigma I)}$$

For rotational ground state band $E_K = 0$

$$R_g = \frac{E4_g^+}{E2_g} = \frac{10}{3} = 3.33 \text{ for rigid rotor } (\sigma = 0)$$

For β – band $E_K = E_{0\beta}$

$$R_g = \frac{E4_\beta^+ - E0_\beta^+}{E2_\beta^+ - E0_\beta^+} = \frac{10}{3} = 3.33 \text{ for rigid rotor } \quad (\sigma = 0)$$

Also, $\Delta E2 = E3_1^+ - (2E2_1^+ + E4_1^+) \gg$

Table – I

Nucleus/Parameters	γ	Rg	R_β	R_γ	ΔE_1(eV)	ΔE_2(eV)
^{228}Ra	11^0	3.21	3.21	-	11.1	566.6
^{228}Th	10^0	3.23	-	2.29	4.2	720
^{230}Th	10.5^0	3.27	3.13	2.24	8.7	545.3
^{232}Th	10^0	3.28	3.26	2.37	4.9	568.6
^{232}U	9.5^0	3.29	3.25	2.33	3.0	659.6
^{234}U	9.0^0	3.29	3.30	2.29	1.1	738.8
^{236}U	9.0^0	3.30	3.20	2.46	1.9	761.5
^{238}U	8.0^0	3.30	3.28	2.27	0.7	867.4
^{240}Pu	8.0^0	3.31	3.33	2.35	2.5	950.5
^{246}Cm	8.0^0	3.31	3.19	2.32	1.6	937.9
^{248}Cm	8.0^0	3.32	3.29	-	-	-
^{250}Cf	8.0^0	3.32	-	2.30	3.1	844.1

The values of γ, R_g, R_β, R_γ, ΔE_1 and ΔE_2 are calculated and listed in table I. The values are tabulated in table – I and are excellently in favour of the rotational structure of these low – lying levels. Whether, this is applicable to all nuclei or to only a few special ones led to an extensive study of the characteristics of the K = 0_2 bands [4].

References:

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