Nuclear structure of multiphonon $\gamma\gamma$-band in neutron rich ^{112}Ru nucleus

Parveen Kumari and H.M. Mittal
Department of Physics,
Dr. B. R. Ambedkar National Institute of Technology,
Jalandhar 144011, Punjab, India

Introduction

The neutron rich ^{112}Ru nucleus (Z=44 and N=68) lie within the A=100 deformed mass region. The experimental study of multiphonon bands was very difficult but now-a-days there are many methods to measure them. Recently, Xing-Lai et al.,[1] investigate the neutron-rich ^{112}Ru nucleus with the gamma-sphere detector array by observing prompt γ-rays of spontaneous fission of ^{252}Cf. They proposed two-side bands, one of them was predicted as two-phonon γ-vibrational band and the another one as two-quasiparticle band. The energy ratio $R_{4/2} = \frac{E(4_1^+)}{E(2_1^+)}$ of the neutron rich ^{112}Ru nucleus is 2.72, this shows that it lie in deformed region. Using cracked shell model, they predicted that in the ground state, the ^{112}Ru nucleus has oblate shape deformation and posses triaxial deformation with increasing rotational frequency. Bohr and Mottelson [2] stated that at $\gamma \geq 24^0$, the nuclei believed to take any shape, including triaxial. In Ref.[3], a number of γ-softness and γ-rigidity signatures in various nuclei has been reviewed and gave most of its attention to the staggering properties of γ-band energies.

In the present work, we study the nature of multiphonon $\gamma\gamma$-band in neutron rich ^{112}Ru nucleus and also calculate the energy value of one-phonon γ-band (K=2) and two-phonon $\gamma\gamma$-band (K=4) by using Modified Soft Rotor Formula (proposed by Gupta et al.,[4]).

Method and Calculations

Brentano et al.,[5] proposed the soft rotor energy formula (SRF) for the ground band and later, Bihari et al.,[6] used this SRF to calculate the energy of one phonon γ-band. They received both the positive and negative values of moment of inertia (MoI) θ_0 and also for softness parameter σ in Ru isotopes and also in many other nuclei. Recently, Gupta et al.,[4] illustrated that it is difficult to justify the negative values of MoI and also the large values of σ. As the softness parameter is only a perturbation correction of MoI [5], so σ is expected to be less than one and should be positive. Gupta et al.,[4] resolved the anomaly of negative MoI and the negative softness parameter σ and also calculate the energy of one phonon γ-band of deformed and shape transition nuclei.

The Modified Soft Rotor Formula (MSRF) is given as:

$$E(I) = EK + \frac{I(I+1)}{2\theta_0(1+\sigma I)}$$

where θ_0 is the MoI parameter and σ is the variable of MoI parameter. For the detail explanation for the calculation of the energy values see Ref.[4]. Here MSRF is true for the corresponding value of $\gamma\gamma$-band MoI $= \frac{3}{E(5\gamma\gamma)-E(4\gamma\gamma)}$, for γ-band MoI $= \frac{3}{E(3\gamma)-E(2\gamma)}$ and ground MoI $\frac{3}{E(2_1^+)}$.

The staggering indices [3] given as:

$$S(I, I-1, I-2) = \frac{(E_I - E_{I-1}) - (E_{I-1} - E_{I-2})}{E(2_1^+)}$$

shows alternative behaviour with spin I. In case of γ-rigid triaxial, the clustering of the γ-band energy levels is predicted, which resulting in an oscillating behaviour of S(I) such that it is negative for odd-spin and positive for even spin levels.

Results and Discussions

The energy levels for ground, γ and $\gamma\gamma$-bands in the neutron rich ^{112}Ru nucleus are

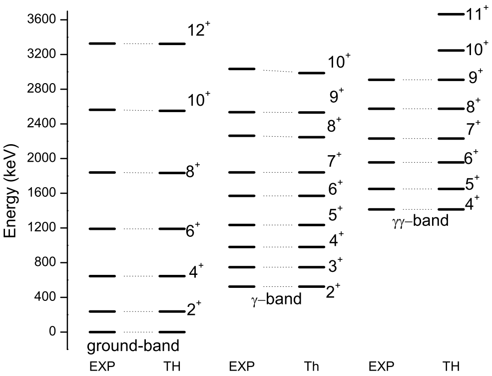

FIG. 1: Comparison between experimental and calculated values of the ground, γ and $\gamma\gamma$- bands energy using MSRF formula.

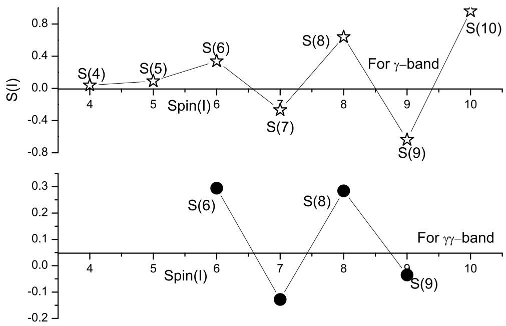

FIG. 2: Staggering indices S(I) is plotted versus spin I using experiment values for ^{112}Ru nucleus for γ and $\gamma\gamma$-bands.

^{112}Ru nucleus	Theoretical MoI	Expt. MoI	σ
Ground band	$\frac{3}{E(2_1^+)} = 0.012$	0.012	0.075
γ-band	$3/(E(3\gamma) - E(2\gamma)) = 0.013$	0.0102	0.099
$\gamma\gamma$-band	$3/(E(5\gamma\gamma) - E(4\gamma\gamma)) = 0.013$	0.0106	0.11

TABLE I: The softness parameter σ, MoI $\theta_{ground-band}$, $\theta_{\gamma-band}$ and $\theta_{\gamma\gamma-band}$ (keV^{-1}) from MSRF. The rotor model $\theta_{grnd} = \frac{3}{E(2_1^+)}$ for ground band, $3/(E(3\gamma) - E(2\gamma))$ for γ-band and $3/(E(5\gamma\gamma) - E(4\gamma\gamma))$ for $\gamma\gamma$-band are listed for comparison.

plotted in Fig.1. The calculated energy values match excellently with the experimental energy for all spin values for ground, γ and $\gamma\gamma$-bands. The experimental data is taken from Ref.[1].

The calculated values of θ_0 and σ for ground, γ and $\gamma\gamma$-bands are listed in Table 1. In the neutron rich ^{112}Ru nucleus, the calculated θ_0 for γ and $\gamma\gamma$-bands are almost equal to the calculated MoI for ground band, which is close to the corresponding rotor model values.

For axial rotor, all the staggering indices S(I) values are positive and increases slowly with increasing spin I and show no zigzag behaviour [8]. The ^{112}Ru nucleus develop a staggering pattern, here the experimental values of S(I) are positive for even spin values and negative for odd spin values for γ-band. The ^{112}Ru nucleus is predicted as γ-rigid triaxial nucleus in γ-band(see Ref.[7]). In case of $\gamma\gamma$-band, ^{112}Ru nucleus show the similar alternating behaviour (see Fig.2). Hence, it is recommended that the neutron rich ^{112}Ru nucleus is γ-rigid triaxial in nature in multiphonon $\gamma\gamma$-band.

References

[1] Xing-Lai et al., *Chin. Phys. Lett.* **23**, 328 (2006).

[2] A. Bohr and B.R. Mottelson, Nuclear Structure Vol. II, *W.A. Benjamin, New York* (1975).

[3] N.V. Zamfir and R.F. Casten, *Phys. Lett. B* **260**, 265 (1991).

[4] Gupta et al., *Pramana J. of Phys.* **81**, 75 (2013).

[5] Brentano et al., *Phys. Rev. C* **69**, 044314 (2004).

[6] Bihari et al., *Phys. Scr.* **77**, 055201 (2008).

[7] McCutchan et al., *Phys. Rev. C* **76**, 024306 (2007).

[8] Liao Ji-Zhi, *Phys. Rev. C* **51**, 141 (1995).