Description of superdeformed bands in Pb isotopes using SU(3) symmetry of Interacting Boson Model

Annanya Mahajan and H. M. Mittal*

Department of Physics, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, Punjab, India (144008)

**mittalhm@nitj.ac.in*

Introduction

The discovery of the high spin superdeformed (SD) bands is one of the historical events in nuclear physics. These SD bands have larger deformation, higher spin, and recognized in the gamma-ray spectra by the appearance of long cascades of γ transitions almost equally spaced in energy. The first superdeformation in the A ≈ 190 mass region was observed in ^{191}Hg [1] and thereafter, more than 85 SD bands were observed in 25 different nuclei. Most SD bands in A ≈ 190 show a smooth increasing trend in the dynamical moment of inertia $\Im^{(2)}$ with increasing the rotational frequency $\hbar\omega$. The rise in $\Im^{(2)}$ results is due to the combined alignment of nucleons in high-j low-Ω intruder orbitals, and the gradual disappearance of pairing correlations with the rotation [2-3]. It has been exhibited that rotational sequences in some SD nuclei with nuclear spins differing by two may divide into two branches. This phenomenon is called ΔI=2 staggering or ΔI=4 bifurcation in the gamma-ray transition energies [4]. The ΔI=1 is another kind of staggering or signature splitting has been noticed in SD odd-A nuclei [5]. It has been observed that most of SD bands in odd-A nuclei in mass region A ≈ 190 are signature partners. The signature partners display the large amplitude ΔI=1, staggering and the band head moments of inertia of each pair are almost identical. In the present manuscript, the authors have employed the SU(3) dynamical symmetry of Interacting Boson Model (IBM) for the first time to determine the band head spin and band head moment of inertia in various superdeformed bands in Pb isotopes in odd A ≈ 190 mass region.

Formalism

To characterize the collective rotational energies, Iachello and Arima [6] proposed the SU(3) dynamical symmetry of IBM model. The energy expression for ground state using the model may be written as

$$E(I) = \frac{\hbar^2}{2\Im}[I(I+1) - \frac{1}{3}(\lambda-\mu)(\lambda+\mu+3)]. \quad (1)$$

Here, $\Im$ is a band head moment of inertia, λ signifies the axial deformation, μ signifies the perpendicular (non-axial) deformation, and I is the spin. As it is well known that the gamma spectroscopy and γ-ray transition energies are only two universally available information for SD bands. The γ ray transition energy E2 for spin level (I) may be written for level I→I-2 as

$$E\gamma = E(I) - E(I-2). \quad (2)$$

The SU(3) energy expression can be expressed in the form of gamma transition energy as

$$E\gamma = \frac{\hbar^2}{2\Im}[I(I+1) - \frac{1}{3}(\lambda-\mu)(\lambda+\mu+3)] - \frac{\hbar^2}{2\Im}[(I-2)(I-1) - \frac{1}{3}(\lambda_0-\mu)(\lambda_0+\mu_0+3)]. \quad (3)$$

Here, λ describes the intrinsic deformation, which is invariant for all energy levels within a given SD band. The entire sequence of energy levels represents the rotational states of a nucleus with this fixed deformation and similarly, μ is invariant for all energy levels in a specific SD band, as the band characterizes different rotational states of the nucleus with the same intrinsic deformation. This dictates that $\Delta\lambda$, $(\lambda - \lambda_0)$ and $\Delta\mu$, $(\mu - \mu_0)$ are zero. Thus above expression in terms of γ-ray transition reduced to

$$E\gamma = \frac{\hbar^2}{2\Im}[I(I+1) - (I-2)(I-1)]. \quad (4)$$

In above Eq., the experimental transition energies reported from chart of nuclides available at nndc website [7] are least square fitted to obtain band head moment of inertia $\Im$. The spins are assigned using Best Fit Method (BFM) by comparing experimental and calculated transition energies. The root mean square deviation (RMSD) which involves the difference between experimental and calculated transition energies are evaluated as

$$\chi = [\frac{1}{n}\sum_{i=1}^{n}(\frac{E_\gamma^{expt} - E_\gamma^{calc}}{E_\gamma^{expt}})^2]^{1/2}. \quad (5)$$

Here, E_γ^{expt} is experimental gamma transition energies and E_γ^{calc} is theoretical gamma transition energies and n is the number of gamma transitions involved in the SD bands. The value of spin at which minimum deviation is obtained between experimental and calculated transition energies is the band head spin I_0. It has been observed that the correct band head spins have been assigned to SD bands in A ≈ 190 mass region in Pb isotopes using SU(3) dynamical symmetry of IBM model (see Table 1). The Figs. 1 and 2 show the variation of χ vs. I_0 for two cases: ^{193}Pb(1) and ^{193}Pb(2). We found from Figs. 1 and 2 that the assigned spin I_0 for ^{193}Pb(1) and ^{193}Pb(2) is 25/2 and 19/2 respectively.

Table 1: The band head spin I and band head moment of inertia ℑ of superdeformed bands in odd A ~ 190 mass region in Pb isotopes using SU(3) dynamical symmetry of IBM model.

SD bands	Spin I_0 ($\hbar$)	Band head moment of ℑ ($\hbar^2$MeV^{-1})
^{193}Pb(1)	**25/2**	**94.86**
^{193}Pb(2)	**19/2**	**100.98**
^{193}Pb(3)	23/2	103
^{193}Pb(4)	25/2	104.69
^{193}Pb(5)	19/2	104.16
^{193}Pb(6)	23/2	107.53
^{195}Pb(1)	11/2	102.04
^{195}Pb(2)	13/2	98.42
^{195}Pb(3)	19/2	107.06
^{195}Pb(4)	19/2	104.16
^{197}Pb(1)	21/2	100.08
^{197}Pb(2)	17/2	98.23
^{197}Pb(3)	17/2	102.04
^{197}Pb(4)	21/2	105.26
^{197}Pb(5)	21/2	102.04
^{197}Pb(6)	19/2	100.40

The various pairs which have almost identical band head moment of inertia are also known as signature partners : ^{193}Pb(4) and ^{193}Pb(5), ^{193}Pb(5) and ^{195}Pb(4), ^{195}Pb(2) and ^{197}Pb(2), ^{193}Pb(2) and ^{197}Pb(6), ^{195}Pb(2) and ^{197}Pb(2).

References

[1] F. M. Moore et al, Phys.Rev.Lett.63 (1989) 360.

[2] J. R. Hughos et al, Phys. Rev.C51 (1995) R 447.

[3] L. P. Farris et al, Phys.Rev.C51 (1995) R2288.

[4] I. Hamamoto and B. Mottelson, Phys. Lett. B 333 (1994) 294, Phys. Sc. T 56 (1995) 27.

[5] A. M. Khalaf et al, Progress in Physics 3 (2013) 39.

[6] F. Iachello and A. Arima, The Interacting Boson Model: Cambridge University Press (1987).

[7] http://www.nndc.bnl.gov/chart/.

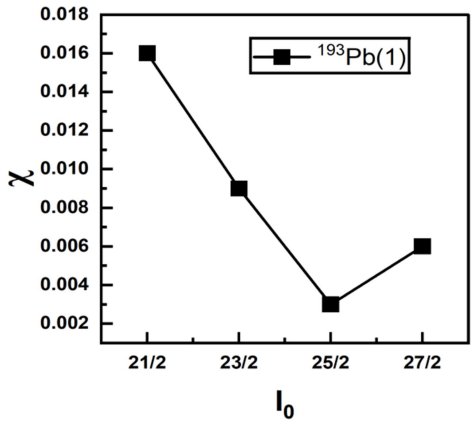

Figure 1: χ vs. I_0 for ^{193}Pb(1) using SU(3) symmetry.

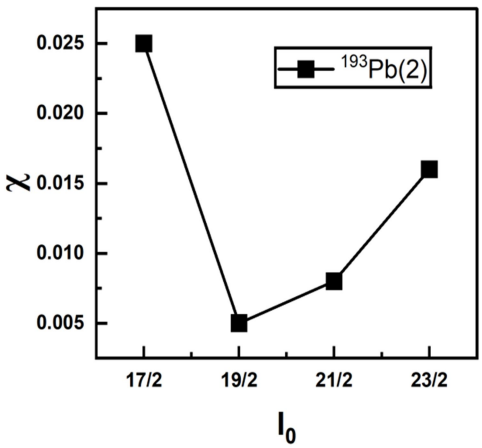

Figure 2: χ vs. I_0 for ^{193}Pb(2) using SU(3) symmetry.