Study of odd-even staggering and multi-phonon bands in ^{152}Sm from interacting boson model

Livinus Emeka Agada and Satendra Sharma***

Department of Physics, Yobe State University, Damaturu, NIGERIA
**Email:agadaman1908@gmail.com ** Email:ss110096@gmail.com*

Introduction

The ^{152}Sm nucleus (Z=62, N=90) is lying between the transition from SU(5) to SU(3) limits of IBM[1]. The N≤88 nuclei are having spherical while the N≥90 nuclei are deformed in nature. For ^{152}Sm, the experimental values [2] of R_4 (=$E4_g/E2_g$) and R_β (=$E0_\beta/E2_g$) are 3.01 and 5.62, respectively and these ratios are very close to the X(5) symmetry limiting values (R_4 = 2.9 and R_β = 5.65). Therefore, ^{152}Sm is the best example of X(5) symmetry of IBM-1 [1].

The large experimental data is available for lower and higher multi- phonon bands from decay and reaction work [2, 3]. The IBM-1 [1] is used to study the energy spectra, B(E2) values/ ratios for inter-band and intra-band transitions. We also test the odd-even spin staggering in γ-band. In the present work, we also studied that whether ^{152}Sm is axially symmetric rotor or rigid triaxial rotor?

The interacting boson model

The Hamiltonian of IBM can be written as:

$$\mathbf{H = \varepsilon'' nd + a_0 (P^\dagger.P)+ a_1 (L.L) + a_2(Q.Q) + a_3 (T_3.T_3)+ a_4(T_4.T_4).} \quad (1)$$

Where,

$$\mathbf{n_d = (d^\dagger . \tilde{d}); P = (1/2)\{(\tilde{d}.\tilde{d}) - (\tilde{s}.\tilde{s})\}}$$
$$\mathbf{L = \sqrt{10}\, (d^\dagger \tilde{d})^{(1)}; Q = [d^\dagger \tilde{s} + s^\dagger \tilde{d}]^{(2)}}$$
$$\mathbf{T_3 = [d^\dagger \tilde{d}]^{(2)} ; T_4 = [d^\dagger \tilde{d}]^{(4)} .}$$

The PHINT [4] is used to get the unique values of ε, a_0, a_1 and a_2 (a_3=a_4=0) parameters for which the energy levels with reliable spin assignment ($I^\pi \leq 10^+$) are the input. These four parameters with E2SD (=α_2) and E2DD (=$\sqrt{5}\beta_2$) are the input for the FBEM [5]. The E2 transition operator can be written as:

$$\mathbf{T(E2) = \alpha_2[d^\dagger \tilde{s} + s^\dagger \tilde{d}]^{(2)} + \beta_2[d^\dagger \tilde{d}]^{(2)}} \quad (2)$$

where α_2 is called the boson effective charge, simply the scaling parameter and affecting the B(E2) values; β_2 accounts for nuclear shape transition.

Result and Discussion

Energy Spectra of Lower and Multi-phonon Bands

The calculated values of energies for g, β_1, γ_1, β_2, β_3, γ_2 and $K^\pi = 4^+$ bands are compared with the experimental values [2, 3] and are given in Table 1.There is agreement between experimental and IBM values of energies for lower and higher multi- phonon bands.

Transition Rate

The absolute B(E2) values for (γ→g) and (β→g) transitions depend on the intrinsic matrix elements and geometrical factors [6]. The B(E2) branching ratio for two transitions from a particular level in a given band to the two states of other band i.e. (Ii→If/If') depends on the Alaga value [6]. In the SU(3) limit these rules are slightly modified because the (γ→g) and (β→g) transitions are prohibited, but in the slightly broken symmetry the (γ→g) transition should be faster that (β→g) transition. The observed B(E2) ratios are obtained from the γ–ray spectrum data, using the relation [7]:

$$\mathbf{B(E2; I_i \rightarrow I_f / I_{f'}) = [I\gamma/I\gamma'] \{E\gamma'/ E\gamma\}^5 .} \quad (3)$$

Where, E_γ and E_γ' are the γ – ray energies for ($I_i \rightarrow I_f$) and ($I_i \rightarrow I_f$') transitions; I_γ and I_γ' are the intensities, respectively.

The BE(2) values and ratios are calculated for inter and intra band transitions (Results will be presented).

Odd-Even Staggering (OES)

The idea of OES in γ-band was given by McCutchan et al. [8] and Zamfir and Casten [9]. Recently, Gupta et al. [10] illustrated that the values of OES index S(4) is close to zero for N=90 (Sm, Gd, Dy) isotones and small for N>90 (Sm, Gd, Dy, Er) well deformed nuclei.

The OES effect represents the relative displacement of the odd spin levels of the γ-band with respect to their neighboring levels with even spin. The band mixing interaction pushes the even spin members in γ-band relative to the odd spin members, due to the interaction with even spin members of the ground band [11]. The OES is calculated by using the expression [8, 9]:

$$S(J) = \frac{[E(J) - E(J-1)] - [E(J-1) - E(J-2)]}{E2_1^+} \quad (4)$$

Table 1: The value of experimental [2, 3] and IBM energies (in MeV) for various bands.

I^π	K^π	IBM1	Expt.	Diff.
2g	0_1^+	0.1315	0.1218	-0.0097
4g	0_1^+	0.3698	0.3665	-0.0033
6g	0_1^+	0.6992	0.7069	0.0077
8g	0_1^+	1.1097	1.1254	0.0157
10g	0_1^+	1.5942	1.6093	0.0151
0_β	0_2^+	0.6649	0.6848	0.0199
2_β	0_2^+	0.8166	0.8105	-0.0061
4_β	0_2^+	1.1495	1.023	-0.1265
6_β	0_2^+	1.5402	1.3105	-0.2297
8_β	0_2^+	1.9983	1.6665	-0.3318
10_β	0_2^+	2.5228	2.0796	-0.4432
2_γ	2_1^+	1.0294	1.0858	0.0564
3_γ	2_1^+	1.1005	1.2339	0.1334
4_γ	2_1^+	1.4366	1.3717	-0.0649
5_γ	2_1^+	1.4807	1.5596	0.0789
6_γ	2_1^+	1.9086	1.7283	-0.1803
7_γ	2_1^+	1.9312	1.9459	0.0147
8_γ	2_1^+	2.4472	2.1397	-0.3075
9_γ	2_1^+	2.4501	2.3755	-0.0746
10_γ	2_1^+	3.0500	2.6625	-0.3875
$0_{\beta 2}$	0_3^+	1.4960	1.0823	-0.4137
$2_{\beta 2}$	0_3^+	1.5890	1.2928	-0.2962
$4_{\beta 2}$	0_3^+	1.7069	1.6129	-0.094
$6_{\beta 2}$	0_3^+	2.2044	2.0042	-0.2002
$0_{\beta 3}$	0_4^+	1.5924	1.6588	0.0664
$2_{\beta 3}$	0_4^+	1.8954	(1.7766)	-0.1188
0_5+	0_5^+	2.3952	1.755	-0.6402
2_6+	2_2^+	1.8799	1.7691	-0.1108
(3_2+)	2_2^+	2.0891	1.9077	-0.1814
4+	4_1^+	2.1268	1.757	-0.3698
5+	4_1^+	2.1672	1.8911	-0.2761
6+	4_1^+	2.6665	2.0401	-0.6264
7+	4_1^+	2.6904	2.206	-0.4844
8+	4_1^+	2.7388	2.3917	-0.3471
9+	4_1^+	3.2660	2.588	-0.678
10+	4_1^+	3.3227	(2.810)	-0.5127

The staggering index S(J) is calculated using Eqn. (4) and its variation with J is shown in Fig. 1. The index of odd-even spin staggering is a quantitative measurement of OES with spin. The experimental value of S(4) is -0.085 while IBM value is 2.015 which is close to the rigid triaxial rotor value of 1.67. This reflects rigid triaxial rotor nature of ^{152}Sm.

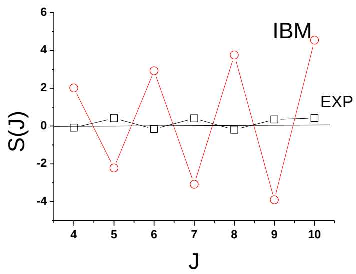

Fig. 1: The variation of OES index S(J) vs. J.

Acknowledgement

We are grateful to Prof. Musa Alabe, Vice Chancellor, Yobe State University, Damaturu, Nigeria for encouragement and for providing the research facilities. Fruitful discussions with Prof. J. B. Gupta are gratefully acknowledged.

References

[1] Iachello F. and Arima A., *The Interacting Boson Model* (Cambridge University Press, Cambridge), 1987.
[2] Martin M J, Nuclear Data Sheets, **114**,1497,2013
[3] http://www.nndc.bnl.gov/nsdf , 2015.
[4] Scholten O., Programme PHINT, KVI internal report **63**, 1979.
[5] Scholten O., Programme FBEM, KVI internal report **63**, 1979.
[6] Bohr A. and Mottelson B. R., Nuclear Structure Vol. II (Benjamin, New York, 1975).
[7] Alaga A., Alderm K., Bohr A. and Mottelson B. R., Dan. Mat, Fys. Medd. **29**, no.9, 1955.
[8] E A McCutchan, et al., Phys. Rev. **C 76**, 024306, 2007.
[9] N V Zamfir and R F Casten, Phys. Lett. **B 260**, 265,1991.
[10] J B Gupta, S Sharma and V Katoch, Pramana J. Phys. **81**, 75, 2013
[11] Casten R. F., *Nuclear Structure from a Simple Perspective*, (Oxford University Press, New York), 1990.