A unique test of shape phase transition, ^{150}Sm an example

J.B. Gupta, Krishna Kumar[1] and J.H. Hamilton[2].
Ramjas College, University of Delhi, Delhi-110007
[1]Tenessee Tech University, Cookeville, TN, USA
[2]Vanderbilt University, Nashville, TN, USA

In the unified collective model of Bohr-Mottelson [1], the nuclei are classified as vibrational or rotational. A nucleus is said to possess a collective structure, if the inter level transitions with E2 character have B(E2) value several times of the single particle unit or Weisskopf unit (WU). In 1950s, ^{24}Mg and ^{25}Mg were cited as good examples of such nuclei, in the light sd-shell region. Later, the actinide region nuclei were found to exhibit rotational spectra in their ground bands. Also the rare-earth region, in the medium mass nuclear region, has been studied intensively. For even Z-even N nuclei, the energy ratio R(4/2)= E(4)/E(2) is a good measure of the nuclear shape, which is about 2.0 for spherical nuclei and equals 10/3 for well deformed nuclei. However, in most nuclei this ratio has a value ranging between these two limits. Recently, Iachello [2] identified a new analytically solvable symmetry called X(5) on the spherical to deformed transition for the axially symmetric nuclei, for which R(4/2) is approximately 2.90. Several N=90 isotones (Nd, Sm, Gd and Dy) are found as good examples of X(5) nuclei. The shape transition at N=88-90 was recognized very early [1]. Thus N=88 nuclei of Nd, Sm, Gd and Dy are regarded as spherical vibrators with R(4/2) equal to 2.511, 2.316, 2.194 and 2.32 respectively.

However, besides the geometrical shape of the nuclear core in the ground state, *the softness of the core is an important factor for the nuclear structure*, which has not been studied so far with a deeper attention. It may be visualized through the B(E2, 2-0) value. This too is reflected in N=88-90 shape transition. But a more subtle test is required, in a case where the energy ratio R(4/2) corresponds to a spherical regime, but the nucleus is soft to β-vibration. $E(0_2)$ =680 keV is low in ^{150}Sm. Naturally, a test for this lies in the behavior of the K=0 β-band and the K=2 γ-band: position on the energy scale, and their decay characteristics. In our study of this region, in the frame work of the microscopic theory as set through the Dynamic Pairing plus Quadrupole (DPPQ) model, we had pointed out the critical balance of the quadrupole force strength X and of the pairing force strength G_0 in their respective terms of the H_{PPQ} [3]. .In fact a slight edge of the former force over the latter, was found to be necessary for a correct evaluation of the theoretical structure in agreement with experiment.

However, a recent study [4] of ^{150}Sm using the Interacting boson model (IBM) [5] proposed it to possess the spherical vibrator structure, which view is different from the DPPQ analysis [3]. *Since the nuclear structure has to be model independent, it was crucial to look at the source of this mismatch.* So have re-analyzed the nucleus in the DPPQ model, which of course, gave the same results as previously. Then we studied ^{150}Sm in the IBM=1, using a two term Hamiltonian

$$H=\varepsilon n_d+kQ\cdot Q \qquad (1)$$

Here we have studied the role of the ratio r= ε/k, acting as the control parameter, in predicting the structure in the IBM frame work. Therein we arrived at a critical value of r_c=39, below which the nucleus looked more rotor like and above which it corresponds to a spherical shape, but with a β-soft rotor dynamic character.

Our test is to see if the level energies should be arranged in vibration phonon multiplets or one having K=0, 2 bands (Fig. 1). In ^{150}Sm, the 2_β and 2_γ level energies are too close, so it is important to identify them properly. Only the right assignment should yield the proper transition characteristics. So we searched for a crucial absolute B(E2) value, using the well recognized fact that an *intra-band transition should be stronger compared to the inter-band transition for a proper K-band*, if it exists.

As illustrated in Fig. 1 we note that for a value of $r < r_c$ one obtains a K-band structure and vice versa. For this lesser value of r, B(E2, $2_2 \rightarrow 0_2$) > B(E2, $2_2 \rightarrow 2_1$) (Fig.2), thus not only supporting the K-band structure in ^{150}Sm but also that the 2_2 state is a K=0 state. Once we chose these IBM parameters, the IBM structure was in better agreement with experiment. Further, we studied the IBM wave functions of these 2^+ states, and unambiguously demonstrated the predominance of n_d =2 component in the 2_2 state. Additionally these IBM parameters also yield a deformed potential well in the intrinsic approach [6]

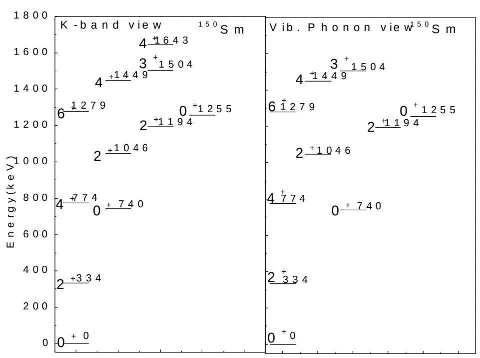

Fig. 1. Two views of energy levels in ^{150}Sm.

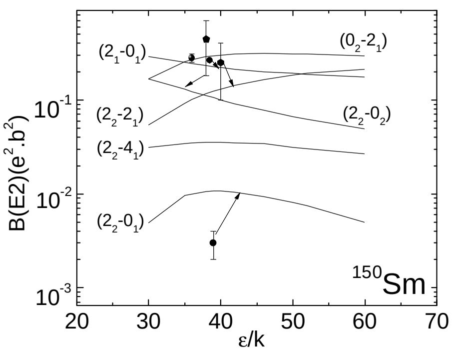

Fig.2. Variation of K=0_2–g-band B(E2) with ε/k in ^{150}Sm.

References

[1] A. Bohr and B.R .Mottelson, *The Nuclear Structure* Vol II (Benjamin) (1975).
[2] F. Iachello, Phys. Rev. Lett. **87**, 2502 (2001).
[3] J.B. Gupta and K Kumar, J Phys.**G7**, 1981 (1981).
[4] H. G. Borner et al. Phys. Rev. **C73**, 034314 (2006).
[5] F. Iachello and A. Arima, *The Interacting Boson Model* (Cambridge Univ. Press) (1987).
[6] J.B.Gupta, K. Kumar and J.H. Hamilton, Int. J Mod. Physics **E19** (7), 1491 (2010).