Nuclear structure of $^{122\text{-}134}$Ba in IBM-1

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The study of shape phase transition in light Ba nuclei with increasing neutron number N is of current interest [1, 2]. With the advent of the Interacting Boson Model IBM-1 [1], and the identification of the three dynamic symmetries U(5), SU(3) and O(6), corresponding to the three limiting symmetries of the collective model, viz. spherical vibrator, axially symmetric deformed rotor and the γ-unstable rotor, it became easier to study the nuclear structure of medium mass nuclei.

The light Ba (N<82) isotopes were cited [2] as good examples of γ-soft rotor or O(6) nuclei. Here, the main interest was in distinguishing between the γ-soft and the γ-rigid or triaxial rotor model [3]. This was done by looking at the odd-even spin staggering in the K=2 γ-band of these nuclei. A cubic d-boson interaction term was used to induce triaxial effects in the IBA model calculation [2].

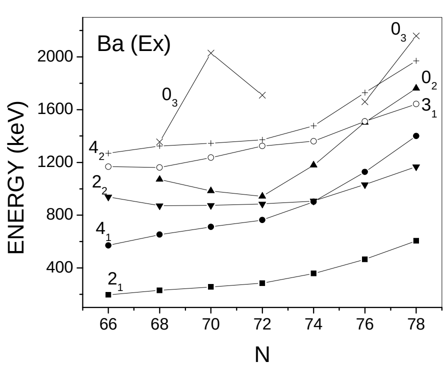

Fig.1. The energy level diagram of $^{122\text{-}134}$Ba.

In the present work, we study the variation of the level energy spectrum with varying N for $^{122\text{-}134}$Ba. In Figure 1, partial level scheme, comprising of 2_1, (4_1; 2_2, 0_2), (3_1, 4_2, 0_3) levels is depicted, taking experimental data from the literature [4]. Here we observe the following pattern of nuclear structure changes in Ba with N:

There is a triplet of states I=4_1, 2_2 and 0_2 and a quintuplet of states (only 3 states shown). Near mid shell at N=66, 4_1 lies pretty low, signifying the prolate deformation in $^{122\text{-}126}$Ba. At N=72 in ^{128}Ba, there is near degeneracy of the triplet. At higher N, in ^{132,134}Ba 2_2 descends below 4_1. Also 0_2 rises high, which is akin to O(6) pattern. The energy ratio $R_{4/2}$ is falling (see Table 1) with increasing N and $R_\gamma = E(2_2)/E(2_1)$ is falling from about 4.8 to 2.2 corresponding to the increase of triaxiality parameter γ_0 from 20^0 to 30^0 (Table 1).

In the N=3 quintuplet, the state I=3_1 touches 4_2 at N=72, and then separates on either side. So one says that ^{128}Ba is O(6) on account of the degenerate 3_1 and 4_2. Like the triplet, in the quintuplet also there is bunching of states near N=72.

We have calculated the level spectra of $^{122\text{-}134}$Ba using the phenomenological IBA model program PHINT [5]. The parameters of the IBM-1 Hamiltonian Eq. (1) [1] are listed in Table 2.

$$H = \varepsilon\, n_d + a_2\, Q\cdot Q + a_1 L\cdot L + a_0 P\cdot P. \qquad (1)$$

The d-boson energy coefficient EPS is relatively large here, and varies with N in a narrow range, except for N=76, 78 where the level structure changes drastically. Similarly, the coefficient of the deformation producing quadrupole term Q·Q varies in a narrow range, except at N=74. It starts reducing and turns positive at N=76, where the state 2_2 goes below 4_1. The other two parameters also vary within a narrow range. We have kept the χ coefficient of the d^+d term in the quadrupole operator fixed at χ=-1.32 (CHQ=√5χ), except for ^{132,134}Ba, where it is reduced to --0.876.

Table 1. The energies of some levels from IBM fit compared with EX.

A=	122	124	126	128	130	132	134
$E(2_1)$ EX	196	230	256	284	357	465	605
IBM	182	230	242	291	379	479	625
$E(4_1)$ EX	570	652	711	763	901	1128	1400
IBM	574	665	676	735	895	1106	1286
$R_{4/2}$ EX	2.90	2.83	2.77	2.68	2.52	2.43	2.32
IBM	3.15	2.90	2.79	2.53	2.36	2.31	2.1
$E(2_2)$ EX	939	872	874	885	907	1032	1168
IBM	898	823	814	825	846	988	1223
R_γ EX	4.79	3.80	3.41	3.11	2.54	2.22	1.93
IBM	4.93	3.58	3.36	2.84	2.23	2.06	1.98
$E(2_2\text{-}4_1)^{EX}$	369	220	163	122	-57	-96	232
IBM	324	207	138	90	-49	-118	-63

Table 2. The parameters of IBM Hamiltonian in MULT form (in keV).

	122	124	126	128	130	132	134
EPS	523.7	600	569.5	563.4	601.7	745.2	695.8
QQ	-21.0	-19,5	-21.3	-21.8	-13.1	+28.5	24.5
ELL	26.6	23.6	20.9	14.9	15.1	24.0	10.3
PAIR	31.6	41.1	36.9	27.7	40.3	92.2	38.5
$\sqrt{5}\ \chi$	-2.96	-2.96	-2.96	-2.96	-2.96	-1.96	-1.96

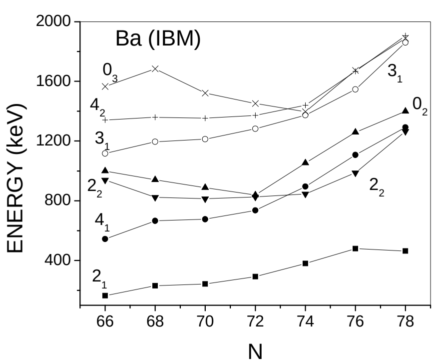

Fig.2 The energy level diagram from our IBA calculation.

The bunching of levels as observed in Fig. 1 is reproduced in IBA (Fig 2). In Table 1, the IBM energies are compared with EX values. Here we focus on $R_{4/2}$, R_γ and $E(2_2)$-$E(4_1)$, respective measures of deformation, γ-triaxiality and prolate oblate potential energy difference. All the three important indicators of level structure are reproduced in our calculation. The movement of 2_2 below 4_1 at N=74 is reproduced. The variation of the $\Delta E=E(2_2)-E(4_1)$ *related to the* V_{PO} *in a given nucleus in the mean field theory and IBM* is well given in our calculation, including its sign change at A=130.

Here we note that decrease of R_γ is not due to the falling 2_2 as in DF diagram [3], but is on account of rising of $E(2_1)$ at fast rate compared to $E(2_2)$, which is even increasing at 72 to 78. The pattern of spectrum here indicates a continuous phase transition from near SU(3) to γ-soft rotor with large γ_0.

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