Observation of triaxiality in the transitional ^{132}Ba nucleus via B(E2↑) measurements

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In the chart of radionuclide, at A≈130 Xe, Ba and Ce-isotopes provide us precious information on both collective and single particle excitations. This is the heaviest mass region where proton and neutron excitations compete within the same major shell (viz. $(g_{7/2})^2$ or $(h_{11/2})^2$). The low-level excitations proposed an indication of triaxiality/γ-softness in the heavier isotopes beyond mid-shell in these isotopes [1-3]. As extremely sharp changes have been observed in nuclear structure with the accumulation of only a pair of nucleons, these transitional shapes play an important role in the sensitivity of interplay of prolate-oblate shape transitions. The low-level structure predicts the nuclear shapes satisfactorily, however, some strong deviations have also occurred from the B(E2) systematics [4]. A simple way to understand these effects is to study the nuclear observables with changing proton and neutron numbers or simply termed as the study of the structural evolution in an isotopic/isotonic chain.

In collective even-even nuclei, the vibrator ($R_{4/2}$=2.0), the symmetric rotor ($R_{4/2}$=3.3), and the γ-soft ($R_{4/2}$=2.5), or axially asymmetric rotor are the three well-known idealized paradigms also termed as U(5), SU(3), and O(6) symmetries in the Interacting boson model (IBM) of Arima and Iachello [5]. As derived by Iachello [5] and discussed in Refs.-3&6 by R. F. Casten, these deformations and symmetries were presented as symmetry triangle and is shown here in Fig. 1 along with the typical low-level energy states. These models have been quite successful in predicting various observables in mid-heavy and heavy mass region of the nuclear chart [1-3,5,6].

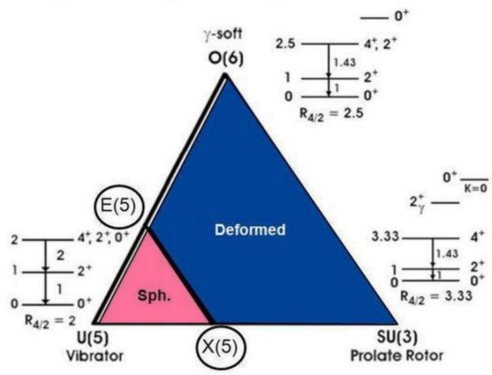

Fig. 2 IBM symmetry triangle for nuclear structure showing the conventional paradigms at the vertices along-with mini-level schemes [3].

A signature of triaxiality and/or γ-softness in nuclei is the presence of 2_2^+ state near to 4_1^+

state. A lower 2_2^+ energy than 4_1^+ state and large B(E2: $2_2^+ \rightarrow 0^+$) is a signature of γ-soft nuclei, whereas lower 2_2^+ energy than 4_1^+ and large B(E2: $2_2^+ \rightarrow 2_1^+$) provide an evidence of triaxial nature. The long chain of Ba-isotopes covers the interplay of p-n interactions between quadrupole deformations in neutron-deficient isotopes to octupole degree of freedom in neutron-rich Ba-isotopes. The emergence of E(5) critical point symmetry between U(5) to O(6) transitional limit, showing second-order phase transition, and lack of the data on B(E2) values motivated us to study the ^{132}Ba nucleus. As low energy Coulomb excitation method is the best way to study the low-level nuclear structure, in particular B(E2↑) values, two Coulomb excitation experiments were carried out to evaluate these nuclei.

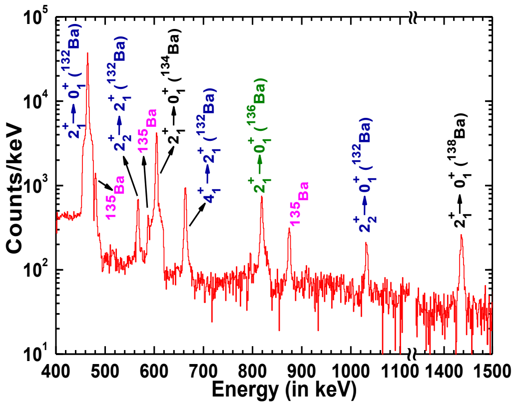

Fig. 2 Energy calibrated & Doppler shift corrected total γ-ray spectrum for ^{32}S+^{132}Ba.

The energy calibrated and Doppler shift corrected total γ-ray spectrum has been shown in Fig. 2. The Gates on PIN diodes' energy and HPGe timings were used to reduce the background radiation. All the observed γ-rays have been tagged in the figure together with the respective transitions. The γ-rays for other Ba-isotopes (^{134}Ba, ^{135}Ba, ^{136}Ba, and ^{138}Ba) were also observed, which were present as an isotopic contamination in the target.

To get more sensitivity on the matrix elements, the observed γ-ray spectrum was divided in to two different particle scattering angular regions i.e. 110º-140º and 140º-170º. A combined input file was created for both the IUAC and HIL data. A χ^2 value of ~0.3 was obtained during the minimization procedure. The necessary mixing and branching ratios are adopted from Ref- 11. The off-line analysis for the determination of B(E2↑) values was performed using well-known Coulomb excitation codes, Winther-de Boer [7] and least squares search code GOSIA [8]. A detailed description of the experimental details and the data analysis procedure for the present systems can also be found in Refs 9&10.

States up to 1127 keV, namely, $2_1^+ \rightarrow 0_1^+$, $4_1^+ \rightarrow 2_1^+$, $2_2^+ \rightarrow 2_1^+$, and $2_2^+ \rightarrow 0_1^+$ in ^{132}Ba nucleus were detected. Preliminary results on B(E2↑) values suggest triaxiality in ^{132}Ba rather than the widely discussed O(6) limit [3,6]. Further analysis, aiming the determination of quadrupole deformation parameter (<cos3δ>), error in matrix elements and there relative signs etc. (as discussed earlier in Ref-12) are in progress and the obtained results along-with the comparison with other available models will be presented during the conference.

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[1] R. F. Casten, Nuclear Structure from a Simple Perspective, 2nd edition, Oxford University Press Oxford (2005).
[2] A. Bohr and B. R. Mottelson, Nuclear Structure, Vol. II: Benjamin NY (1975).
[3] R. F. Casten, Nature Physics **2**, 811 (2006).
[4] M. Saxena et al., Phys. Rev. C **90**, 024316 (2014).
[5] F. Iachello et al., Phys. Rev. Lett. **81**, 1191 (1998).
[6] R. F. Casten, Physics Scr. **91**, 033004 (2016).
[7] A. Winther and J. de Boer, in Coulomb Excitation, edited by K. Alder and A. Winther, (Academic Press, New York /London, 1966).
[8] T. Czosnyka, D. Cline, and C.Y. Wu, Bull. American Phys. Soc. 28, 745 (1983). http://slcj.uw.edu.pl/en/gosia-code/.
[9] S. Dutt et al., DAE Symp. on Nucl. Phys. **61**, 92-93 (2016) & **62**, 64-65 (2017).
[10] S. Dutt et al., Acta Physica Polonica B **47**, 917-922 (2016) & **49**, 535-540 (2018).
[11] A. Gade, et al., Nucl. Phys. A **697**, 75 (2002).
[12] K. Wrzosek-Lipska et al., Phys. Rev. C **86**, 064305 (2012).