# Quest for triaxiality and Wobbling rotation in $^{133}$Ba

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## 1. Introduction

The concept of triaxiality in atomic nucleus was first introduced by Bohr and Mottelson, in which they discussed the possibility of collective rotation about all the three axes, which associates different moment of inertia, of a triaxial even-even nucleus [1]. Wobbling [2] and Chirality [3] are the two attributes of nuclear triaxiality which have been observed so far. In this paper, we discussed triaxiality in $^{133}$Ba nucleus based on the experimental evidences of transverse wobbling in the low lying excited states. One distinguishing feature of a wobbling band is the linking transition of ΔI=1, E2 type between the bands. Experimental evidences for wobbling excitation have been reported first in $^{161,163,165,167}$Lu isotopes and $^{167}$Ta nucleus [4, and references therein]. Possibility of stable triaxial nuclear shape has also been predicted in mass A∼130 region [5] and chirality, which is the complementary phenomena of a triaxial nucleus have been reported in this mass region [4, 6]. Recently, wobbling motion has also been reported in $^{135}$Pr [7] and $^{133}$La [8] nuclei. In the earlier study of the $^{133}$Ba nucleus [9], the band which is discussed as a wobbler in the present paper was reported as one quasi-neutron particle $h_{11/2}$ band. But, it was mentioned that a large $\gamma$ value of deformation parameter is required to explain the observed large signature splitting of the band. In $^{133}$Ba, the particle like quasi-neutron will align its angular momentum along the short axis of the triaxial core and thereby minimizing the interaction energy. In such a scheme, the angular momentum vector of the quasi-neutron is perpendicular to the medium axis which have the largest moment of inertia. This is the condition for a transverse wobbling and therefore, the wobbling excitation in $^{133}$Ba is based on the alignment of a high $j$, $h_{11/2}$ neutron along the short axis of the triaxial core.

## 2. Experimental Details

For this investigation, an experiment was performed to populate the excited states of $^{133}$Ba through the reaction $^{124}$Sn($^{13}$C, $4n$)$^{133}$Ba, with a beam energy of 48 MeV, provided by the 14-UD pelletron at Tata Institute of Fundamental Research (TIFR), Mumbai. The target used was $^{124}$Sn of thickness 1.5 mg/cm$^2$ with $^{197}$Au backing of thickness 6.0 mg/cm$^2$ The $\gamma$-rays were detected by using the Indian National Gamma Array (INGA) spectrometer which consisted of 11 Compton suppressed clover detectors which were placed in a $4\pi$ geometry array with 3, 3, 1 and 4 number of detectors at angles 157°, 140°, 115° and 90°, respectively, with respect to the beam direction.

## 3. Results

The $R_{DCO}$ and the polarization asymmetry ($\Delta$) values were measured to confirmed the nature of the linking transitions. In FIG 1, these values are compared with the values of linking transitions of $^{135}$Pr. The $\Delta > 0$, values, show the predominant electric nature of these transitions and the transitions are stretch in nature. Using the $R_{DCO}$ vs. $\Delta$ contour plot, the mixing ratios ($\delta$) were extracted. It is observed that the transitions have large E2 admixture, upto 81%. The wobbling energies ($E_{wob}$) were also

TABLE I: The mixing ratios ($\delta$), E2 fractions and the experimental transition probability ratios $\frac{B(M1_{out})}{B(E2_{in})}$ and $\frac{B(E2_{out})}{B(E2_{in})}$ for the transitions from $n_\omega = 1$ to $n_\omega = 0$ bands of $^{133}$Ba.

| $I_i^\pi \rightarrow I_f^\pi$ | $E_\gamma$ (keV) | $\delta$ | E2 fraction (%) | $\frac{B(M1_{out})}{B(E2_{in})}$ (expt.) | $\frac{B(E2_{out})}{B(E2_{in})}$ (expt.) |
|---|---|---|---|---|---|
| $\frac{13}{2}^- \rightarrow \frac{11}{2}^-$ | 613.6 | $-1.05^{0.25}_{0.25}$ | $52.44^{11.88}_{11.88}$ | 1.46 ± 0.39 | - |
| $\frac{17}{2}^- \rightarrow \frac{15}{2}^-$ | 743.8 | $-2.07^{0.21}_{0.20}$ | $81.08^{3.11}_{2.96}$ | 2.40 ± 1.4 | 2.86 ± 0.12 |
| $\frac{21}{2}^- \rightarrow \frac{19}{2}^-$ | 812 | $-1.99^{0.14}_{0.14}$ | $79.84^{5.09}_{5.09}$ | 1.50 ± 0.56 | 1.83 ± 0.36 |
| $\frac{25}{2}^- \rightarrow \frac{23}{2}^-$ | 798 | - | - | - | - |

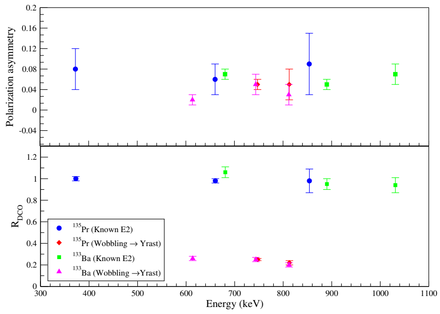


FIG. 1: The $R_{DCO}$ and $\Delta$ for the linking transitions of $^{133}$Ba along with the values for $^{135}$Pr.

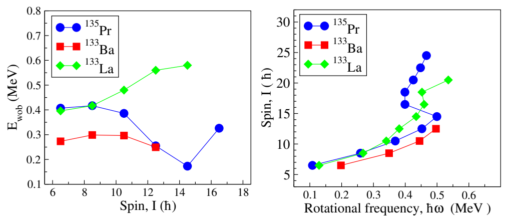


FIG. 2: (a) $I(\hbar)$ vs. $E_{wob}$ plot for $^{133}$Ba, $^{135}$Pr and $^{133}$La. (b) $\hbar\omega$ vs $I(\hbar)$ plot for the yrast band of $^{133}$Ba along with the yrast band of $^{135}$Pr and $^{133}$La.

calculated from the level energies. The $E_{wob}$ decrease with $I(\hbar)$ as shown in FIG 2(a). This behavior of the $E_{wob}$ as a function of spin $I(\hbar)$ in combination with the electric nature of the linking transitions confirms the transverse nature of the wobbling motion in $^{133}$Ba. To ensure the predominant electric nature of the linking transitions, the experimental transition probability ratios $\frac{B(M1_{out})}{B(E2_{in})}$ and $\frac{B(E2_{out})}{B(E2_{in})}$ were also calculated and the values with their corresponding $\delta$ and E2 fraction are summarized in TABLE 1.

## 4. Conclusion

In $^{133}$Ba nucleus, it is cleared that the $E_{wob}$ vs $I(\hbar)$ behavior is very much similar to the $^{135}$Pr and same is also true for the behavior of rotational frequency with respect to $I(\hbar)$ (FIG 2(b)). Therefore, $^{133}$Ba nucleus is a possible candidate for transverse wobbling which arises due to a quasi-neutron particle in $h_{11/2}$. In this letter, we report the first observation of wobbling excitation which established from the alignment of a neutron. In the previously reported cases, the odd particle which is responsible for the wobbling excitation are protons.

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