

# A systematics study of the rotational bands in the $A \sim 250$ mass region

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## Introduction

Since the moment Mendeleev first organized the elements into the periodic table, a key question in the field of natural sciences has been centered on determining the heaviest chemical element that can be encountered in nature or fabricated by human intervention. Notably, the heaviest known nuclei possessing a “magic” number of both protons and neutrons is  $^{208}\text{Pb}$ . Coulomb repulsion between the protons grows significantly beyond proton number  $Z=82$ . The examination of the next proton and neutron shell closures and, consequently, an island of greater stability occupies a central position in the field of nuclear structural studies. It is proposed that to generate a chemical element, the composite nuclear system must survive for  $10^{-14}$  seconds. This much time is necessary for the creation of the complex nucleus [1]. A superheavy element (SHE) is defined as one in which a macroscopic fission barrier computed would lead to a lifetime even lower than this time limit. The existence of SHE is purely predicated on the shell effects, which provide it with increased stability and finite lifetimes. The quest for superheavy elements (SHE) receives a boost through the identification of elements with  $Z=110-116$  [2].

## The vibration distortion model

In the domain of low-lying nuclear energy spectra, the coupling between vibration and rotation is critically significant. Utilizing an analogous effect observed in the vibration and

rotation of nuclei and molecules, the vibrational distortion model has been introduced [3]. In scenarios involving molecules with rotational and vibrational degrees of freedom, the excitation energy can be formulated as follows:

$$F_\nu = (B_\nu - D_\nu I(I+1))I(I+1), \quad (1)$$

where  $\nu$  represents the vibrational frequency. Drawing inspiration from this expression and experimental evidence of octupole vibrational modes, the moment of inertia can be expressed as a function that integrates both rotational and vibrational distortions. This approach is formulated as follows:

$$\mathfrak{I}^{(2)} = \mathfrak{I}_c^{(2)} \pm \mathfrak{I}_{vib}^{(2)} [\omega_{max} - \omega/\omega_{max}]^2, \quad (2)$$

where  $\mathfrak{I}_c^{(2)}$  and  $\mathfrak{I}_{vib}^{(2)}$  represent the constant and the vibrational components of the dynamic MoI, respectively. The term accounting for frequency-dependent vibrational distortion can be ascribed to a cluster-like or binary structure within the nucleus at elevated spin levels. Direct observation of this phenomenon is feasible through the measurement of the dynamic MoI, providing insights into these complex nuclear behaviors.

## Results and Discussion

For the rotational bands in the  $A \sim 250$  mass region, we suggest adopting a  $((\omega_{max} - \omega)/\omega_{max})^n$  dependence on  $\mathfrak{I}_{vib}^{(2)}$ , where  $n$  is a free parameter. For this particular mass region, we have selected  $n = -2$ . The dynamic MoI for rotational bands within  $N = 148$  to 152 isotones has been thoroughly analyzed using the modified vibrational distortion model. In the isotonic series ranging from  $N = 148$  to 152, thirty-six rotational bands have been

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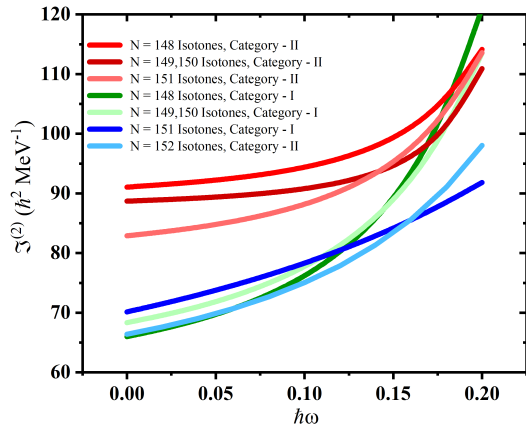


FIG. 1: The variation of average  $\mathfrak{I}^{(2)}$  with  $\hbar\omega$  for all categories combined of rotational bands in  $N=148$  to  $152$  isotones.

analyzed using a parameter setting of  $n = -2$ , yielding remarkable agreement with the experimentally observed dynamic MoI. The analysis of the dynamic MoI across various categories of  $N = 148$  to  $152$  isotones, as shown in figure 1, reveals three distinct patterns. These categories reflect different nuclear behaviors in response to increasing rotational frequency (up to  $0.20$  MeV).

**1.** Category II of  $N = 148, 149, 150,$  and  $151$  Isotones (Red Curves): This category is characterized by a higher starting value of dynamic MoI ( $\approx 90 \hbar^2 \text{MeV}^{-1}$ ), with a marked and abrupt rise after reaching a rotational frequency of  $0.2$  MeV. This steep increase suggests a significant change in the configuration of the nucleus.

**2.** Category I of  $N = 148, 149,$  and  $150$  Isotones (Green Curves): In this pattern, the dynamic MoI begins at a lower value ( $\approx 65 \hbar^2 \text{MeV}^{-1}$ ) and shows a more gradual increase

with the rotational frequency. Interestingly, these bands converge with the red curves at  $\sim 0.2$  MeV frequency. Despite starting from different dynamic MoIs, this convergence suggests a similar nuclear response to rotational stress at higher frequencies.

**3.** Category I of  $N = 151$  and Category II of  $N = 152$  Isotones (Blue Curves): These bands initially follow a similar trend to Category I of  $N = 148, 149,$  and  $150$  isotones, exhibiting a smooth increase in dynamic MoI up to  $0.2$  MeV. They merge with the green lines at lower frequencies but eventually diverge due to variations in the vibrational distortion term.

## Conclusion

This research marks the first instance where the dynamic moment of inertia in the mass region around  $A \sim 250$  is explored using a semi-classical vibrational distortion model. In this context, we suggest a novel modification to the term representing vibrational distortion. For the mass region  $A \sim 250$ , it is proposed that this term be defined as  $((\omega_{\text{max}} - \omega)/\omega_{\text{max}})^n$ , where  $n$  represents an adjustable free parameter. As a result, the dynamic MoI may be thought to have a rather weak dependence on their respective nucleonic configurations.

## References

- [1] P. T. Greenlees, J. Rubert, J. Piot, B. J. P. Gall, L. L. Andersson, M. Asai, Z. Asfari, D. M. Cox, F. Dechery, O. Dorvaux, et al., Phys. Rev. Lett. **109**, 012501 (2012).
- [2] Y. T. Oganessian, V. K. Utyonkov, Y. V. Lobanov, F. S. Abdullin, A. N. Polyakov, I. V. Shirokovsky, Y. S. Tsyganov, G. G. Gulbekian, S. L. Bogomolov, B. N. Gikal, et al., Phys. Rev. Lett. **83**, 3154 (1999).
- [3] S. Roy, Phys. Rev. C **94**, 064329 (2016).