Effect of isospin on the damping of nuclear giant dipole vibration

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Introduction

High energy γ-ray emitted due to the decay of isovector giant dipole resonance (IVGDR) is an interesting probe to study nuclear structure and dynamics. Further, the Brink-Axel hypothesis opened the opportunity to investigate hot and rotating nuclei using IVGDR as a probe [1]. In the liquid drop picture, GDR can be viewed as an out-of-phase vibration of neutron and proton fluids. Over the years, several experimental efforts have been made to explore the new behavior of this collective oscillation. Also, various theoretical models have been proposed to reveal the physics behind such a behavior. Among these, the classical thermal shape fluctuation model (TSFM) is partially successful in explaining the increase of IVGDR width with nuclear temperature (excitation energy). In our recent work, we presented an improved version of TSFM by employing microscopic inputs from the finite-temperature density functional theory [2]. In TSFM, it is assumed that IVGDR vibration couples to the nuclear shape degrees of freedom, and the observed IVGDR response function is the weighted average over all possible shapes. Earlier, IVGDR widths were measured for Mo isotopes ^{92,100}Mo, where ^{100}Mo is relatively soft compared to the other one [3]. Contrasting behavior of the width was found for these two isotopes. For ^{92}Mo, the width was found to increase monotonically, whereas it was relatively flat for ^{100}Mo. The observed difference was attributed to the shell effect up to the highest temperature studied. This motivates us to carry out a similar comparative study in another mass region. In the present work, we have chosen two even isotopes of zinc: ^{62}Zn and ^{68}Zn. Such a study is important from the experimental point of view since there is very limited data available in this mass region.

Calculations

The IVGDR line-shape can be represented by a Lorentzian distribution function given by,

$$\mathcal{F} = C_n \frac{NZ}{A} \sum_{\{x_i\}} \frac{E^{*2}\ \Gamma_{x_i}}{\left(E^{*2} - E_{x_i}^2\right)^2 + \left(E^{*}\Gamma_{x_i}\right)^2}, \quad (1)$$

where N, Z, and A has usual meaning. The sum in Eq.(1) is performed over the three body-fixed principle axes of a deformed configuration. For the resonance energy and resonance width, we considered the following empirical relations

$$E_{x_i} = E_0 \left(\frac{R_0}{R_{x_i}}\right) \text{ and } \Gamma_{x_i} = \Gamma_0 \left(\frac{R_0}{R_{x_i}}\right)^{1.6} \quad (2)$$

where, $E_0 = 18.0A^{-1/3} + 25.0A^{-1/6}$ and Γ_0 is the ground state IVGDR width of the nucleus. For both isotopes, we have taken the same value of ground state width at 6.5 MeV. In a standard TSFM, one considers a pure ellipsoidal shape. We have eliminated this restriction by performing a self-consistent calculation. In this calculation, higher-order multipole moments are optimized self-consistently and hence define nuclear shape more accurately. In order to account for this effect, instead of defining nuclear radius in terms of

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Hill-Wheeler coordinates β and γ, we took

$$R_{x_i} = R_0 \exp\left[\frac{{x_i}^{\text{rms}} - x_{i0}^{\text{rms}}}{x_{i0}^{\text{rms}}}\right], \qquad (3)$$

We have considered β and γ as independent coordinates to consider shape fluctuations at finite temperatures around the equilibrium shape. Then, the resultant distribution function has been obtained by performing a weighted average over the (β, γ) surface and is given by

$$\langle \mathcal{O} \rangle = \frac{\int_\beta \int_\gamma D[\beta,\gamma]\; P(\beta,\gamma)\; \mathcal{O}}{\int_\beta \int_\gamma D[\beta,\gamma]\; P(\beta,\gamma)}, \qquad (4)$$

where $P(\beta, \gamma)$ being the probability to attain a particular shape with (β, γ), and it is given by,

$$P(\beta,\gamma) \propto \exp\left(-\frac{F(\beta,\gamma,T) - F_0}{T}\right). \qquad (5)$$

Here, F is the Helmholtz free energy calculated at different temperatures by solving the finite temperature Hartree-Fock-Bogoliubov equation self-consistently. Skyrme parametrization SkM* has been used in the interaction. Pairing strength for both the isotopes have been adjusted to reproduce the ground state pairing gap. The strengths $V_0^n = -329$ MeV, $V_0^p = -353.3$ MeV and $V_0^n = -290.5$ MeV, $V_0^p = -347.5$ reproduce the ground state pairing gaps of ^{62}Zn and ^{68}Zn respectively. These strengths pairs were used in whole self-consistent calculation. Symmetry unrestricted DFT solver HFODD has been used for this purpose. Details can be found in Ref [2]. The present calculation is restricted to $\gamma = 0$, i.e., to only axially symmetric shapes.

Results and Conclusion

Helmholtz free energy curves for both isotopes are shown in Fig. 1. For both nuclei, ground states are spherical. It is clearly evident from Fig. 1 that free energy rises more slowly with deformation in ^{68}Zn than ^{62}Zn. This ensures the contribution of larger deformations with higher probabilities. Effectively, it results in a higher IVGDR width as the temperature increases. This nature is reflected in the temperature dependence in Fig. 2. It is clear from this figure that the width increases more rapidly with temperature in ^{68}Zn than the other. In order to get a complete picture, a more involved two-dimensional calculation over the entire (β, γ) plane is needed, which is under progress.

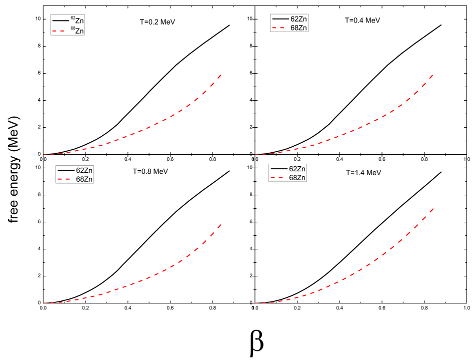

FIG. 1: β dependence of free energy curves for ^{62}Zn and ^{68}Zn at different temperature calculated using the SkM* parameters of the Skyrme energy density functional.

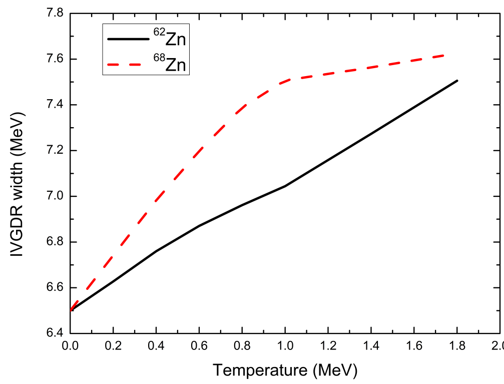

FIG. 2: Behaviour of IVGDR width with temperature of the nucleus.

References

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