# A linear response theory for GDR

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## Introduction

Giant dipole resonance (GDR) presents the best tool to probe the collective mode oscillations of the nucleus resulting in a prominent peak in the photo-absorption/emission cross-section of the nucleus [1]. GDR primarily refers to the isovector mode of GDR, which is the most prominent mode among all the giant resonances. In the present work, we investigate the GDR under the microscopic framework of linear response theory [2] with the calculations employing a triaxial Wood-Saxon (WS) potential. While explaining the recent experimental findings reported in Ref. [3], we also present a comparison with the macroscopic approach.

## The Microscopic Model

The nuclear structure is modeled with WS potential, and to calculate the response function we use a residual dipole-dipole interaction between the nucleons. In the intrinsic frame, the Hamiltonian of the system is given by [2]

$$\hat{H} = \hat{H}_0 + \frac{1}{2}\sum_{\alpha=1}^{3} \kappa_\alpha \hat{D}^\dagger_\alpha \hat{D}_\alpha, \qquad (1)$$

where $\hat{H}_0$ is the single-particle Hamiltonian with the WS potential. $\kappa_\alpha$ is the strength parameter of the dipole-dipole force, and $\hat{D}_\alpha$ is the single-particle dipole operator where $\alpha$ represents the three spatial directions. The response function matrix $R$ can be calculated using the linearised Bethe-Salpeter equation [1], with matrix elements given by,

$$R_{\alpha\beta} = \frac{R^0_{\alpha\beta}}{1 - R^0_{\alpha\alpha}\kappa_\alpha}, \qquad (2)$$

where $R^0$ is the response function without the residual interaction. Self consistent values of coupling strengths ($\kappa_\alpha$) [2] are obtained from the structure of the nucleus calculated with $\hat{H}_0$ and are the function of deformation parameters $\beta, \gamma$. Here $R^0_{\alpha\beta}$ depends upon the width which is chosen to be energy dependent [4]. The cross-section in the intrinsic frame can be calculated as [2]

$$\sigma(E,\beta,\gamma) = \frac{-4\pi e^2 E}{\hbar c}\sum_{\alpha=1}^{3}\mathrm{Im}[R_{\alpha\alpha}(E,\beta,\gamma)], \qquad (3)$$

where $E$ is the energy of the photon.

## The Macroscopic Model

In the macroscopic model, GDR observables are dependent upon the nuclear shapes (for more details, see Refs. [5, 6]). The total GDR cross-section ($\sigma$) is the sum of the Lorentzians with peaks at resonance energies ($E_\alpha$) and can be written as [5]

$$\sigma(E) = \sum_\alpha \frac{\sigma_\alpha}{1 + (E^2 - E^2_\alpha)/(E^2\Gamma^2_\alpha)}, \qquad (4)$$

where $\sigma_\alpha$ and $\Gamma_\alpha$ are the peak cross-section and full width at half maximum, respectively.

## Results and Discussions

The most probable shape of the nucleus is obtained by minimizing the potential energy surface (PES) calculated using a macroscopic-microscopic approach using the WS potential with universal set of parameters [7] as shown in Fig. 2. In Fig 1, we present our results obtained with both microscopic and macroscopic models and compare them with the recent experimental data [3]. The GDR cross-section is calculated at values of $\beta, \gamma$ given in Ref. [8]

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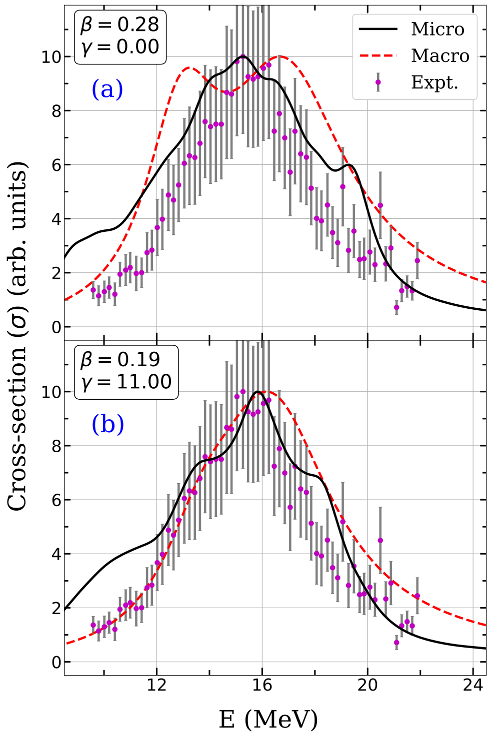


FIG. 1: Experimental GDR cross-sections of $^{148}$Nd (filled-circles) taken from Ref. [3] are compared with the microscopic (black solid line) and macroscopic (red dashed line) model calculations: (a) At $\beta$ = 0.28 taken from Ref. [8], (b) At $\beta$ = 0.19; $\gamma$ = 11° calculated using PES shown in Fig. 2.

[Fig. 1(a)] and at the most probable shape obtained from the PES [Fig. 1(b)]. Overall, both models reproduce the experimental GDR cross-section well within the experimental uncertainties. While the microscopic model turns out to be more versatile model in both cases, the macroscopic model is inconvenient in the 10 - 14 MeV region if the deformation values are taken from Ref. [8]. Both models are found in good agreement with each other and with experimental data while considering the deformation values obtained from the minimum of the PES [Fig. 1(b)]. In the microscopic model, a significantly higher GDR

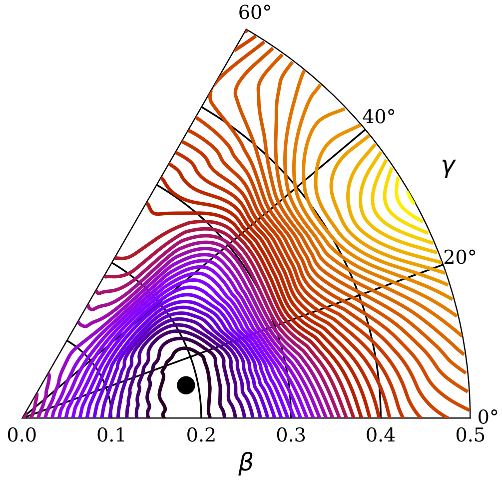


FIG. 2: PES of $^{148}$Nd with contour line spacing of 0.2 MeV. The black filled circle represents the minimum at $\beta = 0.19, \gamma = 11°$.

strength exists in the 8 - 10 MeV region. This enhancement is known to be due to the Pygmy dipole resonances which the microscopic calculations cannot distinguish from the GDR. Further investigation into the nature of response function in the 8-10 MeV region can shed more light in this regard.

## References


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