Empirical determination of all parameters in phenomenological description of giant dipole resonance

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Introduction

Giant Dipole Resonance (GDR), is one among the fundamental modes of collective excitations of protons against neutrons with a dipole spatial pattern in nuclei caused by the photons. The microscopic approaches describe GDR as a coherent superposition of particle-hole excitations, often called p-h doorway resonance). The macroscopic approaches couple GDR to the quadrupole shape degrees of freedom) and are successful in explaining most of the GDR features. In other words, the structure of the GDR cross section can be linked with the deformation parameters defining the shape of nuclei. In the present work we investigate a global fitting of all parameters involved in this method.

Details of calculation

In the model considered for present work, GDR cross sections are obtained using a rotating anisotropic harmonic oscillator potential and a separable dipole-dipole residual interaction [1,2]. The final set of GDR frequencies in laboratory frame for non rotating axially symmetric nuclei are obtained as

$$\begin{aligned} \widetilde{\omega}_z &= (1+\eta)^{1/2}\omega_z \text{ and} \\ \widetilde{\omega}_2 &= \widetilde{\omega}_3 = (1+\eta)^{1/2}\omega_\rho \ , \end{aligned} \tag{1}$$

where $\omega_\rho = \omega_x = \omega_y$ and ω_i are the oscillator frequencies given by the deformation parameters.

By the semi classical theory of the interaction of photons with nuclei, the shape of a fundamental resonance in the absorption cross-section is that of the Lorentz curve

$$\sigma(E_\gamma) = \sum_i \frac{\sigma_{mi}}{1 + \left(E_\gamma^2 - E_{mi}^2\right)\ ,^2 / E_\gamma^2 \Gamma_i^2} \tag{2}$$

where Lorentz parameters E_m, σ_m, Γ are the resonance energy, peak cross-section and full width at half maximum respectively. Here i represents the number of components of the GDR and is determined from the shape of the nucleus. It is to be noted that these Lorentz lines are non-interfering, but Γ_i is assumed to depend on energy. The energy dependence of the GDR width can be approximated by [3]

$$\Gamma_i \approx 0.026 E_i^{1.9} \tag{3}$$

where E_i are the GDR energies. The peak cross section σ_m is given by

$$\sigma_m = 60 \frac{2}{\pi} \frac{NZ}{A} \frac{1}{\Gamma} 0.86(1+\alpha) \ , \tag{4}$$

where α is an adjustable parameter which takes care of the sum rule. The other parameter η which denotes the strength of the dipole-dipole interaction is normally varied for every nucleus to obtain the proper ground state GDR centroid energy. For calculating the GDR width, only the power law [3] is used in this formalism and no ground state width is assumed. If we assume spherical symmetry, Eq. (1) reduce to

$$\widetilde{\omega}_z = \widetilde{\omega}_2 = \widetilde{\omega}_3 = (1+\eta)^{1/2}\omega \tag{5}$$

where $\omega = \omega_x = \omega_y = \omega_z$. The quantity $(1+\eta)^{1/2}\hbar\omega$ should be equal to the centroid energy in the spherical case. If we use the experimental centroid energy for spherical nuclei, we can get the values of η empirically using the relation

$$\eta = \frac{E_{Expt.}^2}{(\hbar\omega)^2} - 1 \ . \tag{6}$$

Results

The dipole-dipole interaction strength (η) calculated using Eq. (6) and the experimental

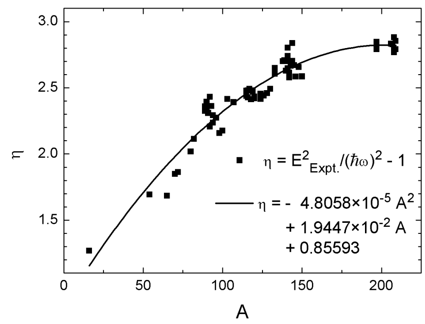

FIG. 1: The dipole-dipole interaction strength (η) as a function of mass number. The solid squares correspond to η obtained from experimental [4] GDR centroid energies for spherical nuclei and the line denotes a best fitting second order polynomial displayed in the inset.

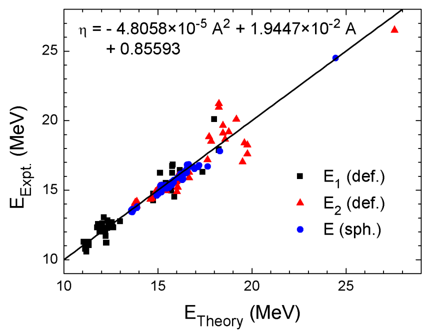

FIG. 2: Comparison between theoretical and experimental [4] values of GDR centroid energies.

centroid energies are shown in Fig. 1. A second order polynomial has been fitted for this data and the resulting best fitting curve also is shown in Fig. 1.

To check the validity of the parameterization of η, we have used the fitted polynomial to calculated the centroid energies of spherical as well as deformed nuclei listed in Ref. [4]. For deformed nuclei the GDR energies depend on the deformation parameter β_2 which is taken from Ref. [5]. The resulting energies are plotted against the experimental energies in Fig. 2 where we can see the fit to be almost exact for spherical cases and exemplary for deformed nuclei. The fit for the other parameters in Eqs. (3) and (4) yielded results similar to previous efforts.

Conclusions

An empirical relation between dipole-dipole interaction strength (η) and A is established for the first time. With that empirical relation for η and using deformation obtained theoretically we can reproduce the experimental GDR energies accurately. Empirical fit between GDR width and centroid energy is improved and hence a complete and global set of parameters are made available for GDR calculations.

References

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