Determination of the nuclear deformation via the giant dipole resonance width at finite temperature

Deepak Pandit[1*], Balaram Dey[1], Debasish Mondal[1], S. Mukhopadhyay[1], Surajit Pal[1], Srijit Bhattacharya[2], A. De[3] and S. R. Banerjee[1]

[1]Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata – 700064, INDIA
[2]Department of Physics, Barasat Govt. College, Barasat, N–24 Pgs, Kolkata – 700124, INDIA
[3]Department of Physics, Raniganj Girls' College, Raniganj – 713347, WB, INDIA
* email:deepak.pandit@vecc.gov.in

Giant resonances, the collective mode of excitation of the nuclei, are of particular interest because they currently provide the most reliable information about the bulk behavior of the nuclear many body system. The prime example of the polarization mode of collective nuclear vibration is the giant dipole resonance (GDR) in which protons and neutrons oscillate out of phase. Since the centroid energy of the resonance is inversely proportional to the nuclear radius, the GDR strength function splits in the case of a deformed nucleus and the deformation can be estimated from the ratio of the two resonance energies [1]. However, for small deformations, the separation is not appreciable and the two resonance energies cannot be identified individually. As a result, the overall width of the GDR increases.

A wealth of GDR data, built on excited states, has shown that the apparent GDR width increases with both angular momentum (J) and temperature (T) and the behaviour can be described reasonably well within the Thermal Shape Fluctuation Model (TSFM) [2]. However, the model fails to explain the experimental data below T < 1.5 MeV in different mass regions [3]. Recently, it has been shown that the discrepancy between the experimental data and the TSFM predictions at low T is due to the competition between the GDR induced fluctuation (β_{GDR}) and the variance of the deformation ($\Delta\beta$) leading to a critical temperature (T_c) in the increase of the GDR width. A new phenomenological model has been proposed by invoking this idea and is called the Critical Temperature included Fluctuation Model (CTFM). The model gives an excellent description of the GDR width systematics for both T and J over the entire mass region [4].

Interestingly, the increase of the apparent GDR width as a function of both J and T can be explained by the deformation induced widening. Hence, in principle, there should exist a correlation between the width of the GDR and the average deformation of the nucleus at finite T and J. Earlier, it was shown within the TSFM that $\langle\beta\rangle$ is directly correlated with the quantity $(\Gamma(J,T,A)-\Gamma_0)/E_0$, where Γ_0 and E_0 represent the width and centroid energy of the GDR for a spherical nucleus, respectively [5]. However, the ansatz failed to represent the temperature dependence of $\langle\beta\rangle$ deduced from the experimental data with the TSFM calculation, as it did not take into account the fluctuations introduced by the GDR motion. We remark here that the width of the GDR and $\langle\beta\rangle$ of the nucleus cannot be directly compared as GDR vibration itself produces a fluctuation and cannot probe the variation that are smaller than its own fluctuation [4]. In fact, $\langle\beta\rangle$ should be correlated to the width of the GDR along with the deformation induced by GDR motion (β_{GDR}). In Fig.1(a), we plot $\langle\beta\rangle$ as a function of $(\Gamma - \Gamma_0)/E_0$ for ^{63}Cu, ^{120}Sn and ^{208}Pb as systematic data exist for these nuclei over a wide range of T [4]. The GDR width was derived from CTFM while $\langle\beta\rangle$ was calculated under the TSFM framework using the Boltzmann probability $e^{-F(\beta,\gamma)/T}$ with the volume element $\beta^4\sin(3\gamma)d\beta d\gamma$ [6]. It can be clearly seen from Fig.1a that the correlation is not linear as different nuclei have different slope as well as different intercept. However, a linear relation is indeed obtained when $\langle\beta\rangle - \beta_{GDR}$ is plotted as a function of $((\Gamma - \Gamma_0)/E_0)^{D(A)}$ (Fig.1b). We propose the correlation between the average deformation of the nucleus and the width of the GDR as

$$\langle\beta\rangle = 0.18 + \beta_{GDR} + 0.7*((\Gamma - \Gamma_0)/E_0)^{D(A)} \quad (1)$$

where, $\beta_{GDR} = 0.04 + 4.13/A$

$D(A) = 2 - 0.0036*A.$

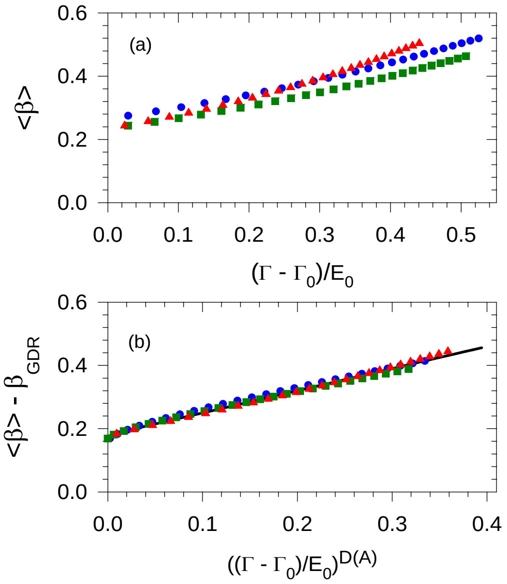

Fig.1. Average nuclear deformation vs GDR width for ^{63}Cu (circles), ^{120}Sn (squares) and ^{208}Pb (triangles) for T < 3.5 MeV and J=15$\hbar$.

The different experimental data, extracted using the proposed correlation, was found to be in good agreement with the TSFM calculation in the entire mass range [7]. In order to verify this correlation further, a series of experiments were performed to measure the GDR width at low temperature (0.8 – 1.3 MeV) in ^{97}Tc using the alpha beams from the K-130 room temperature cyclotron. We calculated the critical temperature (T_c) for ^{97}Tc by comparing $\Delta\beta$ and β_{GDR} as shown in Fig.2a. As can be seen, β_{GDR} and $\Delta\beta$ are equal at T = 1.06 MeV consistent with the prediction of T_c = 0.7 + 37.5/A [4]. Next, we calculated the empirical deformation from the GDR widths measured for ^{97}Tc [8] using Eq.1 and compared it with the TSFM calculation as a function of T. The GDR centroid was obtained from the systematic $E_0 = 31.2A^{-1/3} + 20.6A^{-1/6}$, while the spherical width was calculated using the relation $\Gamma_0 = 0.05E_0^{1.6}$. It is very interesting to note that the experimental data are in very good agreement with the TSFM calculation (Fig. 2b). The experimental data and TSFM differ below T_c because the GDR vibration cannot view the thermal fluctuations that are smaller than its own intrinsic fluctuation. We also compare the <β> extracted from the new data for ^{128}Ba [9] (which has a very large ground state

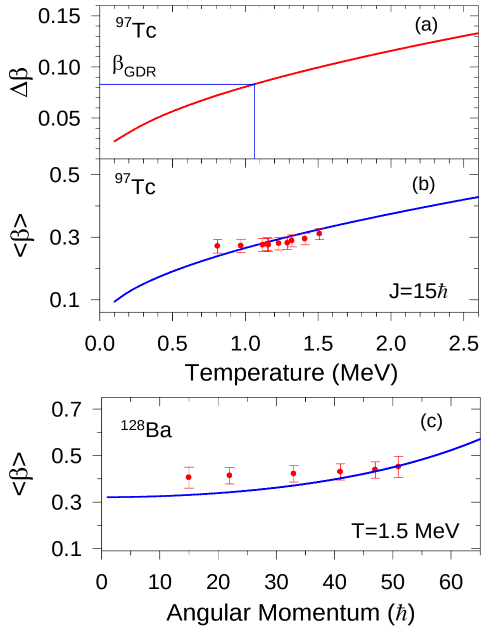

Fig.2. (a) Comparison of $\Delta\beta$ with β_{GDR} for ^{97}Tc to extract the critical temperature. (b) Average deformation determined from the GDR width (circles) for ^{97}Tc and compared with TSFM (solid line) as a function of T. (c) Average deformation determined from the GDR width (circles) for ^{128}Ba and compared with TSFM (solid line) as a function of J.

deformation $\beta \sim 0.218$) as a function of J with TSFM (Fig.2c). Interestingly, in this case too, the experimental data and TSFM match exceptionally well with each other. Hence, this universal correlation between <β> and Γ(T,J,A) provides a direct experimental probe to determine the nuclear deformation at finite T & J and a new insight into the modification of the TSFM to explain the GDR width at low T.

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