Giant dipole resonances built on very highly excited states in nuclei

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The giant dipole resonance (GDR) is a collective excitation of the nucleus. In a macroscopic picture the resonance is described as a vibration of all protons versus all neutrons within the nucleus. The GDR built on excited states of the compound nuclei (CN) is studied by detecting the high energy gamma-rays that emerge from the decay of the resonance. Those gamma-rays are emitted during the early stages of CN decay in competition with the particle evaporation and fission modes and are therefore very much sensitive to the nuclear properties of the state on which the resonance is built. The GDR strength is coupled with the nuclear quadrupole shape degrees of freedom making it possible to study the nuclear shapes at extreme conditions of temperature (T) and angular momentum (J). The GDR gamma-rays are also used as a clock to find out the nuclear dynamics in fusion and fission studies.

The GDR line shape has three parameters, width, strength and centroid energy, most important of them is the GDR width (Γ) which conveys the information of nuclear structure and the damping mechanism prevailing within the nuclear matter in extreme conditions of excitation. Although the evolution of Γ with T and J has been the focus of many experimental studies in the past, a complete understanding of the width systematics is still lacking. The primary motivation in this thesis work is to understand the dependence of the width on T and J. To undertake such a study, the BaF2 array 'LAMBDA' [1] has been used. The array is specially designed and fabricated at the Variable Energy Cyclotron Centre, Kolkata for the measurement of high energy gamma-rays.

The parametrization of GDR width on T and J given by Kusnezov et al. [2] based on the Thermal Shape Fluctuation Model (TSFM) predicts the systematics well, but fails to predict the experimental data at higher J and low T values. The amount of existing experimental data, in which J and T have been measured simultaneously, within the above-mentioned domains of J and T is very scanty and more over those data show conflicting results. Under the circumstances the present thesis revisits the GDR in ^{113}Sb – a near Sn nucleus and provides new results at higher spins (40-60$\hbar$) and low T (T < 2MeV) region to find out the limitations of TSFM.

The fabrication of the detector array is a very involved process. The high energy gamma array 'LAMBDA' [1] has 162 elements, each BaF2 crystal having 3.5 x 3.5 cm2 square face and 35.0 cm in length. The bare crystal was first wrapped with teflon cloth, aluminium foil and electrical black tape for maximum light collection, light tightness. Then it was coupled with photomultiplier tube using uv-ray transmitting grease. Finally the complete assembly was covered with PVC tube for mechanical stability. The α-impurity present inside each crystal was found to be less than 0.3 counts/sec/cc. Individual crystal was calibrated for energy using low energy gamma ray sources and high energy cosmic muons. The energy and time resolutions of the detectors were estimated as 19-20% at E=662 keV and 960 ps [1]. A part (7x7=49) of the array was used in this work. The response function of the array was simulated using Monte Carlo code GEANT 3.21 between E=4-32 MeV. A nearest neighbor cluster summing technique was used for the event reconstruction in simulation and experimental data analysis both. A 50 element multiplicity detector (BaF2) assembly was also fabricated for simultaneous measurement of J study. A part of the assembly (24-element) was used in the experiment done for this thesis work.

High energy gamma spectra were measured with the 7 x 7 array, kept at a distance of 50 cm with an angle of 550 with the centre, in coincidence with the low energy yrast gamma rays in the reaction ^{20}Ne+^{93}Nb at E_{lab}=145 and 160 MeV. The 24-element assembly of multiplicity was kept on the two sides of the target chamber at a distance of 10 cm from target. Using Time of Flight spectra and two-dimensional energy spectra neutron and pile-up events were rejected. Cosmic muons were rejected effectively by triggered coincidence measurement and nearest neighbor event reconstruction. The angular momentum information was extracted from the multiplicity spectrum and the high energy gamma-spectra were grouped into fold 2, 3, 4, 5 (Fig. 1) and more according to the selection of different regions of the observed multiplicity fold spectra.

The experimental data was analyzed [3] using statistical model code CASCADE incorporating pre-equilibrium loss which was estimated using existing parametrizations. Since the high energy gamma ray spectrum contains gamma rays emitted from all the nuclei along the CN decay chain, the T and J of the CN were averaged over all the decay steps. During averaging, a lower limit in E* was applied which affected only the lower energy part of the high energy gamma spectrum without affecting the GDR region. Using this limit, average A, Z, T and J were estimated and those correspond to the approximately 50% of the total high energy (12-25 MeV) gamma yield in the CN decay chain. The centroid energy remains constant with E* but the GDR width changes rapidly with T and J in the region $T_{av} < 2$ MeV and $J_{av} = 41\text{-}60\hbar$. The GDR widths estimated in this way were compared with the predictions of Kusnezov parametrization. It predicts the T dependence rather well but fails in case of J-dependence.

The existing experimental data for $J=40\text{-}60\hbar$ and T<2MeV along with our data were re-analysed using the above-mentioned approach of averaging and pre-equilibrium correction. Remarkably, almost all the data match very well with the theory (Fig. 2), if the ground state GDR width parameter (Γ_0) is taken from the available ground state systematics, but with a 1.5 factor smaller in magnitude [4]. Thus the ambiguity in theoretical TSFM has been resolved within the range of T =1-2 MeV and for higher values of J.

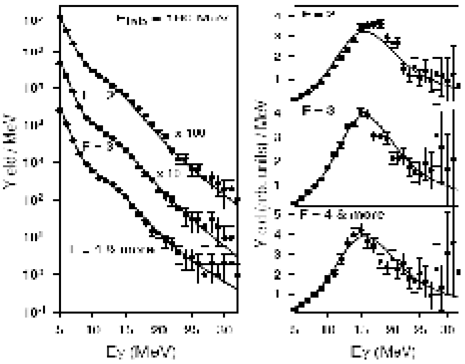

Fig. 1. Left: High energy gamma-spectra at E_{lab}=160 MeV. Right: Linearized plots for different folds.

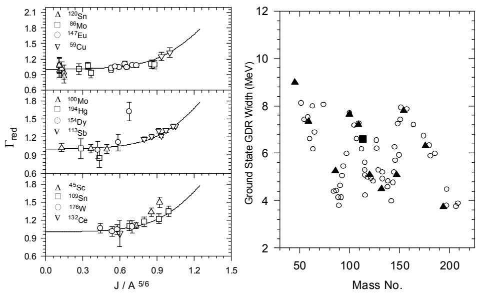

Fig. 2. Reduced width plots (left panel) for various re-analyzed systems and the extracted Γ_0 parameter compared with the systematics of g.s. GDR widths (right panel)

References

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