Evolution of fluctuation and thermal phase transition in nuclei

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The quantum phase transition refers to an abrupt change in the state of a many-body system at zero temperature (T) induced by variation of a non-thermal control parameter. In atomic nuclei, it is connected with the shape transition from spherical to deformed or from axially deformed to nonaxially deformed shapes [1]. Interestingly, the ground state deformation of the nuclei, owing to shell effects, can also be altered by increasing the excitation energy. The thermal excitations weaken the shell effects and act in the direction of decreasing the equilibrium deformation leading to a thermal phase transition from deformed to spherical shape [2]. However, the central issue for a finite system at finite temperature has been the thermal fluctuations present in almost all realms of physics. In the case of atomic nuclei, these fluctuations lead to an average shape which may be completely different from the equilibrium shape. The theoretical calculations based on finite-temperature mean-field theory have been employed to study the nuclear shape transition. These calculations often predict sharp phase transitions at finite temperature even though the sharp phase transition is expected to be washed out due to statistical fluctuations [3] since the nucleus is a finite system. In this scenario, whether the T-driven shape transition will be evident experimentally, still remains an open question. One of the experimental probes to study the shapes and fluctuations of hot nuclei is the giant dipole resonance (GDR) [4, 5]. The GDR strongly couples with the nuclear shape degrees of freedom and hence, in the case of deformation it splits into different components providing direct information about the nuclear deformation. Thus, in order to investigate the long standing question, the thermal phase transition in atomic nuclei, from prolate deformed shape to spherical shape, was studied experimentally by measuring the γ rays from the decay of the GDR in ^{169}Tm (β = 0.3).

The ^{169}Tm compound nucleus was populated through the reaction ^{4}He + ^{165}Ho at four beam energies 32, 37, 42 and 50 MeV by using the K-130 room temperature cyclotron. The high-energy GDR γ rays were detected at 90^0 and 125^0 angles with respect to the incident beam direction by employing the LAMBDA spectrometer [6], arranged in a 7 × 7 matrix, at a distance of 50 cm. The 50-element low-energy γ multiplicity filter [7] was used to estimate the angular momentum (J) populated in the compound nucleus. The filter was split into two blocks of 25 detectors and was placed on the top and the bottom of the scattering chamber. A master trigger was generated when at least one detector each from the top and bottom blocks fired together in coincidence with a high-energy γ ray (> 5 MeV) measured in any of the large detectors in the LAMBDA array. This ensured a selection of high-energy photons from the higher part of the spin distribution free from background. The neutron and the pile-up events in the LAMBDA spectrometer were rejected by time of flight and pulse shape discrimination techniques, respectively.

The high-energy γ ray spectra measured at different beam energies are shown in Fig. 1. It is very interesting to find that the two components of the GDR (around 12 and 16 MeV) are directly visible in the high-energy spectrum at 32 MeV beam energy indicating a large deformation independent of any model. The GDR parameters at different beam energies were obtained by comparing the experimental data with the statistical model calculations (CASCADE). Recently, the collective enhancement effect on the nuclear level density was studied in the same reaction at two beam energies of 28 and 40 MeV [8]. Hence, the same enhanced level densities,

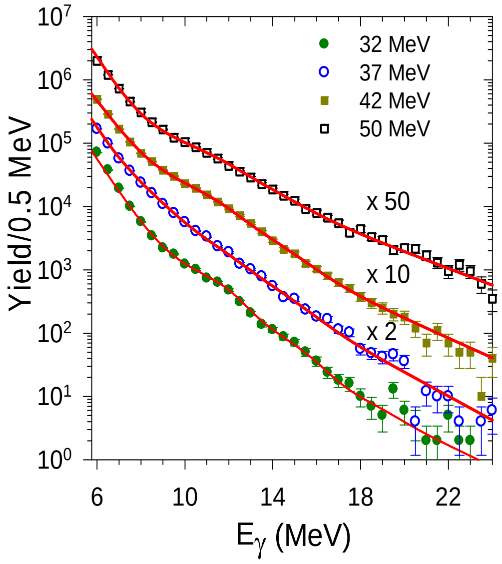

Fig. 1. The experimental spectra measured at an angle of 90^0 at different beam energies are compared with the results of the statistical model calculations plus a bremsstrahlung component.

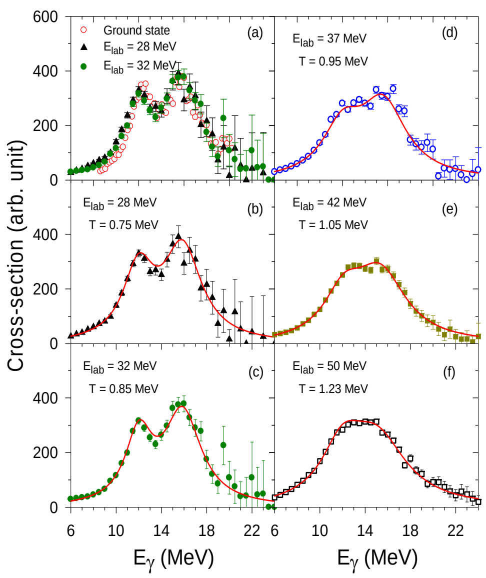

Fig. 2. The linearized GDR strength functions at different beam energies. The data at 28 and 32 MeV are compared with the available ground state photoabsorption cross section for ^{170}Yb. The solid lines are the best-fit two component Lorentzian used in the cascade calculation.

deformation parameters, asymptotic NLD parameter (A/8) and transmission coefficients were used in the statistical model calculation at all the beam energies to explain the experimental data. The linearized GDR plots along with the best fit CASCADE spectra are shown in Fig. 2.

The data at 32 MeV are compared with the ground-state photo absorption cross section in this mass region and also with our earlier data at 28 MeV [8] in Fig 2a. As can be seen, our results are in very good agreement with the ground state cross section confirming that the shape of the nucleus at these excitation energies is indeed prolate, with deformation very similar to that of the ground state value. We emphasize here that spectra, at all the beam energies, could not be explained considering a one component Lorentzian (spherical). It is also remarkable to observe that the effect of fluctuation is seen directly in the experimental data. The two peaks are clearly separated below T = 0.9 MeV showing no effect of fluctuation. However, above T ~ 1 MeV, the two peaks start to become broader due to the averaging effect of thermal fluctuations and finally get convoluted at T ~ 1.2 MeV but the two GDR peaks remain almost unchanged which unambiguously determines the deformation. Thus, the results clearly highlight that the shape of the nucleus still remains prolate with similar deformation as the ground state value at these excitation energies. However, the shape fluctuations about the equilibrium shape are quite large at higher T seen directly in the present study. These interesting results, along with the theoretical calculations, will be presented and explained during the conference.

References

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