Shape transition from collective prolate to spherical as a function of temperature in ^{169}Tm nucleus via GDR γ-rays

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Most nuclei have ground states with non spherical intrinsic shapes caused by the microscopic shell effects arising due to the nucleon-nucleon interactions. Interestingly, for every non-rotating deformed nucleus there exists a critical temperature T_c, where the thermal excitations melt the shell effects and the equilibrium shape of a non-rotating nucleus is spherical. In the case of a hot rotating nucleus, one expects an oblate spheroid rotating about its symmetry axis. However, it has also been shown within the Finite-temperature Hartree-Fock-Bogoliubov (FTHFB) formalism by Goodman [1] that, in many even-even nuclei, there is a temperature interval T_{c1} and T_{c2} ($T_{c1}<T_{c2}$) where the rotation of the hot spherical shape generates a non-collective prolate spheroid i.e. deformed collective rotation below T_{c1}, prolate non-collective rotation between T_{c1} and T_{c2} and finally a transition to oblate non-collective rotation at T_{c2}. These shape transitions are predicted to occur for neutron rich nuclei in Z =72-80 and A = 110-126.

The measurement of the spectral shape and the angular distribution of the GDR photons provide important information of shape transition in nuclei at finite temperature and fast rotation [2,3]. Until now, the shape transition from deformed ground state to spherical shape at higher temperatures had been carried out using heavy ion beams [3,4]. These reactions invariably produce the nuclei at high excitation energies where the shell effects have almost melted. Interestingly, with alpha beams from the K-130 cyclotron, the deformed nuclei can be populated at low temperatures and gradual shape changes can be studied effectively. Here we report on the theoretical calculation of shape transition in ^{169}Tm nuclei, having large ground state deformation, and can be populated by the reaction ^{4}He + ^{165}Ho at low temperatures (T<1).

The spectral shape transition has been studied under the frame work of macroscopic-microscopic model. The macroscopic energy was calculated using the Yukawa folding potential [2] while the microscopic energies were estimated using a deformed Woods Saxon mean-field with the universal parameters [5] and Strutinsky's prescription of shell correction [6]. The minimum free energy at different temperatures for a prolate (γ=0) and an oblate (γ=60) are shown in Fig. 1. As can be seen, the ground state of ^{169}Tm has a prolate deformation of β~0.3. The free energy surfaces in terms of deformation parameter β and γ illustrates the expected transition from well-deformed prolate, near the ground state, to spherical or oblate shapes of small deformation at high temperature (T > 1.5 MeV) (Fig. 2). The calculations were performed at J=20ħ.

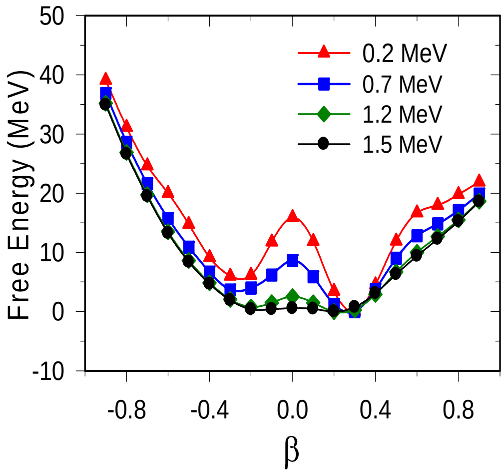

Fig. 1. The free energy minimization (minimum normalized to 0 at different T) as a function of deformation at different T and J = 20ħ. Here positive β represents a prolate shape and negative β an oblate shape.

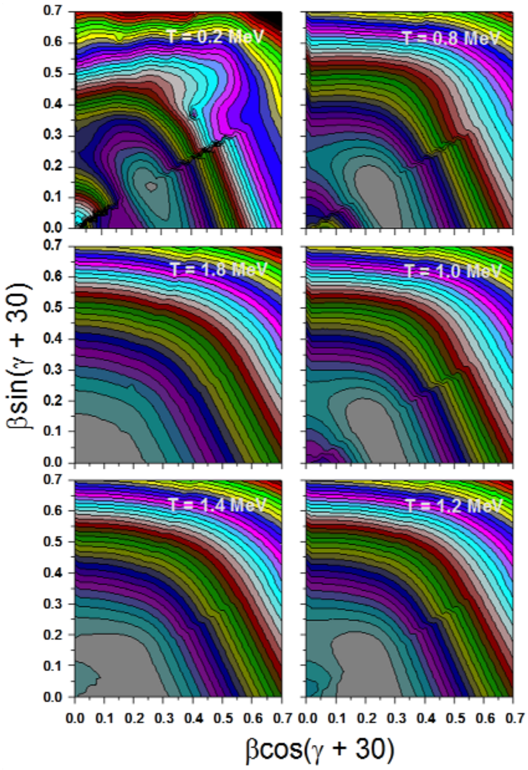

Fig. 2. The free energies surfaces at different T (increasing T clockwise from top left) and J =20ℏ. The non-collective oblate shape is γ=60° (y-axis) and the collective prolate shape γ=0°.

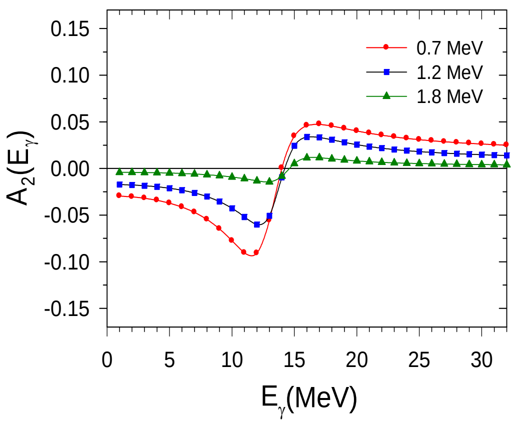

Fig. 3. Angular distribution coefficients as a function of the gamma-ray energy for equilibrium deformation at different temperatures. For T = 0.7 - collective prolate (β ~ 0.3), T = 1.2 - collective prolate (β ~ 0.17) and T = 1.8 – non collective oblate (β ~ 0.03).

Recently, it has been shown that the effect of thermal fluctuations have almost no effect on the GDR lineshapes below a critical temperature (T ~ 1 MeV) [7,8,9]. Macroscopically it is interpreted due to the GDR induced quadrupole moment while microscopically it is explained by taking into account the fluctuations in the pairing field [10]. Thus, populating the ^{169}Tm well below and above T = 1 MeV, at low J, should provide a signature of the shape change from a collective prolate to spherical shape. Experimentally, the angular anisotropies are studied by fitting the experimental data at different angles with the expression $W(\theta) = W_0(1 + A_2P_2(\cos(\theta)))$ where θ is the angle between the emitted γ-rays and the beam-axis. The A_2 coefficient for equilibrium shapes (not including shape and orientation fluctuations) at different T is shown in Fig 3. As can be seen, the decreasing nature of A_2 as a function of T should provide a signature of the shape transition. Moreover, the fluctuations will be smaller at low T and the shape should correspond to the equilibrium one while at higher T the magnitude of A_2 should be further reduced [3] due to the shape and orientation fluctuations providing the evidence of the shape transition.

Thus, using the alpha beams from 28-60 MeV provided by the K-130 cyclotron, we plan to study the shape transition in reaction ^{4}He + ^{165}Ho since the ^{169}Tm nuclei can be populated from T ~ 0.7 to T~1.5 MeV.

References

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