The study of deformation of hot ^{113}Sb at high spin from TSFM and Kusnezov parameterization

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Introduction

The study of the shape transition of hot compound nucleus at large excitation energy and angular momentum is highly interesting. The giant dipole resonance (GDR) strength function is useful as a probe to understand the nuclear shape evolution of compound nuclei at high spins (J) and temperatures (T). The existing thermal shape fluctuation model (TSFM) can be used effectively to interpret the GDR strength function and equilibrium deformations in hot nuclear systems. In this paper, a theoretical calculation has been performed using the TSFM under the framework of rotating liquid drop model (RLDM) to understand the evolution of shape change in the hot and rotating compound nucleus ^{113}Sb with J and T. The variation of the quadrupole deformation parameter (β) in the reaction ^{20}Ne (E_{lab}=145, 160 MeV) + ^{93}Nb has also been studied experimentally as a function of T and J and it is compared with the theoretical predictions.

Method

At high temperature limit, the nuclear free energy at a particular J can be approximated as

$$F = E_{LDM} + \frac{\hbar^2 J(J+1)}{2\cdot I_{zz}} - a\cdot T^2 \qquad (1)$$

where β and γ are the intrinsic quadrupole deformation parameters, a is the level density parameter and I_{zz} is the principal moment of inertia (deformed) along the direction of spin (assumed to be the largest) [1]. E_{LDM} is the deformed liquid drop energy, calculated in terms of β and γ. The moment of inertia was calculated using Hill-Wheeler parameterization. The contributions from shell correction are assumed to be very small and neglected as in this case T ~ 2 MeV.

In an experiment done at VECC, the nuclear reaction ^{20}Ne (E_{lab}=145, 160 MeV) + ^{93}Nb was performed and high energy γ rays were studied using the spectrometer 'LAMBDA'. The angular momentum of the compound nucleus (J_{CN}) was extracted using the 24-element multiplicity filter array [2]. The procedure of estimation of the average J from the initial values of the compound nuclear angular momentum i.e the J_{CN} has been shown in ref. [3]. The GDR observables (E_{GDR},Γ_{GDR}) are calculated using the formula,

$$\Gamma^{i}_{GDR} = \Gamma_0 \left(\frac{E^{i}_{GDR}}{E_0} \right)^{\delta} \qquad (2)$$

where, Γ_0 and E_0 are the ground state GDR width and centroid energy, δ is taken as 1.9. This procedure gives three GDR frequencies and widths along three unequal axes of the nucleus corresponding to a particular J and equilibrium shape.

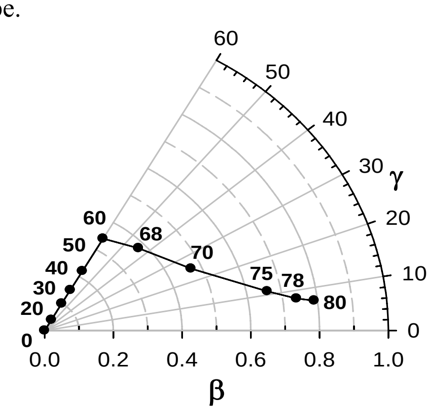

Fig. 1 The equilibrium shapes are plotted as a function of β-γ for different spins. The discrete spins are represented with the data points.

The frequencies (the ones perpendicular to the spin axis) can further split due to Coriolis Effect as the GDR vibration in a nucleus couples with its rotation when viewed from non-rotating frame producing five GDR components [4].

The TSFM predicts that at high T and J, the GDR vibration samples an ensemble of shapes around the equilibrium shape of the compound nucleus. Thus, GDR lineshapes are generated by the TSFM averaging the GDR strength function over the free energy surfaces in the entire deformation space.

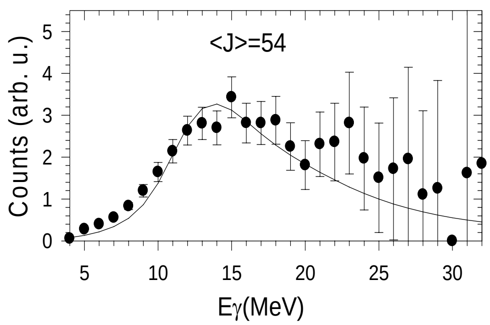

Fig. 2. The TSFM generated lineshape (solid line) is compared with expt. data (filled circles).

Result

The free energy surfaces were obtained for different J's at T = 2 MeV for ^{113}Sb over the entire β and γ spaces to understand the evolution of the nuclear shape from oblate to triaxial and finally to prolate before fission. The evolution is very clear from the polar β-γ plot (Fig. 1) for discrete spins. With the increase in angular velocity, the nucleus becomes more & more oblate deformed ($\gamma = 60^0$) and after J = 60ħ the nucleus suddenly becomes triaxial ($60^0 < \gamma < 0^0$) and approaches towards the prolate shape ($\gamma = 0^0$). Around J ~ 60ħ, that transition is called Jacobi shape transition. The angular momentum for fission is at J ~ 80ħ, In the next step including the TSF model and Coriolis effect, GDR lineshapes are produced for different <J> values. The GDR lineshapes thus produced at different J values are compared with the experimental line shapes (shown in Fig. 2 for a particular <J> = 54ħ).

The β-values for ^{113}Sb at different J and T values are also extracted according to the

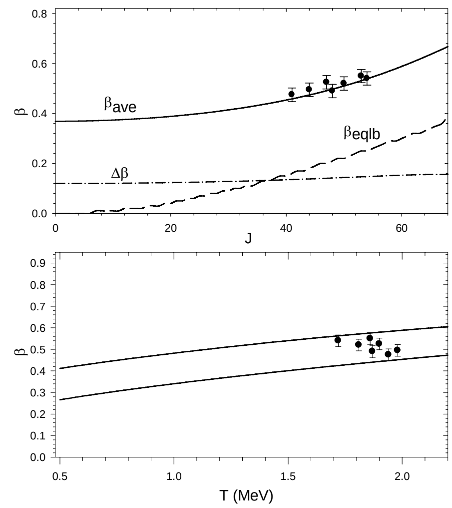

Fig. 3. top. The extracted average β values are plotted with J and compared with the TSFM prediction (solid line). The TSFM predicted equilibrium β (dashed line) and the spread Δβ (dott-dashed line) in deformation are also shown for ^{113}Sb with T = 2.0 MeV. bottom. β values are plotted with T. The upper and lower solid lines represent the TSFM predictions keeping J = 60ħ and 40ħ, respectively.

parametrization of Kusnezov [5] using the experimental GDR widths [2]. The ground state GDR width is taken as per the prescription given in the ref. [3]. Those β parameters are compared with the thermal average β calculated in the TSFM framework and found to be matching successfully (Fig. 3). The variance (Δβ) of the mean β and the equilibrium β values are also plotted with J in Fig. 3. As long as $\beta_{eqlb} < \Delta\beta$, neither the mean β nor the GDR width increase significantly. This is illustrated in the Fig. 3.

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