Role of thermal shape fluctuations on isoscalar giant quadrupole resonance in hot and rotating nuclei

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Introduction

The combined effect of rotation and thermal excitation on nuclear structure has been an intriguing subject for a long time. Such hot rotating nuclei are formed in heavy ion fusion reactions where transfer of energy and angular momentum of the relative motion excites the compound nucleus. The compound nucleus decays through particle and γ-ray emission. The properties of the hot rotating nuclei are studied usually by observing these decay patterns. One of the main expected prospect of using recently developed multi detector arrays is the more accurate study of shape transitions in hot rotating nuclei. At these high excitation energies, giant resonances have been proved to be unique and effective probes. Giant resonances can occur with different modes: monopole, dipole, quadrupole etc. For each of these modes isoscalar and isovector modes can exist. Isoscalar mode is the one in which the protons and neutrons oscillate in phase so that the change in isospin projection $\Delta T_3 = 0$. This mode doesn't depend on the isospin projection of the nucleons and all the nucleons move as one entity. However, in the isovector mode the protons and neutrons oscillate in opposite phases so that $\Delta T_3 = 1$. In the present work, we discuss the role of thermal shape fluctuations on isoscalar giant quadrupole resonances (ISGQR) in hot and rotating nuclei.

Theoretical framework

A distorted Fermi liquid drop model (FLDM) is used to calculate the energies of the ISGQR which can be viewed as small amplitude collective oscillations in which the protons and neutrons undergo in-phase, incompressible and irrotational flow. In this macroscopic approach [1,2], the ISGQR energies can be directly linked to the deformation of oblate nuclei. For shape calculations we follow the Nilsson-Strutinsky (NS) method extended to high spin and temperature [3,4]. The total free energy ($F_{\rm TOT}$) at fixed deformation is calculated using the expression

$$F_{\rm TOT} = E_{\rm RLDM} + \sum_{p,n} \delta F \ . \qquad (1)$$

Expanding the rotating liquid-drop energy $E_{\rm RLDM}$ and writing shell corrections in rotating frame leads to

$$F_{\rm TOT} = E_{\rm LDM} + \sum_{p,n} \delta F^{\omega} + \frac{1}{2}\omega(I_{\rm TOT} + \sum_{p,n} \delta I) \ . \qquad (2)$$

The angular velocity ω is tuned to obtain the desired spin given by

$$I_{\rm TOT} = \Im_{rig}\omega + \delta I \ . \qquad (3)$$

The liquid-drop energy ($E_{\rm LDM}$) is calculated by summing up the Coulomb and surface energies corresponding to a triaxially deformed shape defined by the deformation parameters β and γ. The rigid-body moment of inertia ($\Im_{rig}$) is calculated with surface diffuseness correction. The shell corrections (δF^{ω},δI) are obtained with exact temperature and spin dependence using the single-particle energies and spin projections given by the triaxial Nilsson model.

At finite temperature and fixed spin the ISGQR energies are averaged out by integrating over a Boltzman factor involving the deformation energies.

$$\langle E_{GQR} \rangle_{\beta} = \frac{\int e^{-F(T,I;\beta)/T} E_{GQR}(\beta) d\beta}{\int e^{-F(T,I;\beta)/T} d\beta} \ . \qquad (4)$$

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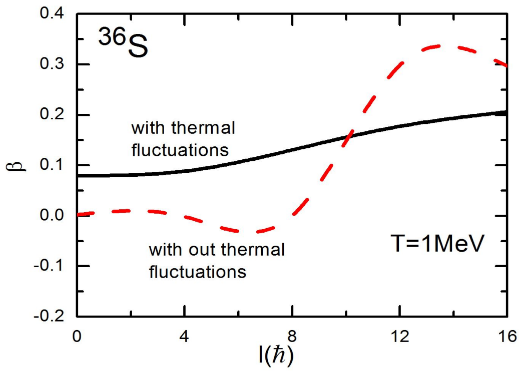

FIG. 1: Dependence of deformation parameter (β) over spin (I). The average value of the deformation over the temperature is plotted against the spin for temperature $T = 1$ MeV (with fluctuations). The minimised value of β is also plotted (for which the energy is minimum) against the spin (without thermal fluctuations).

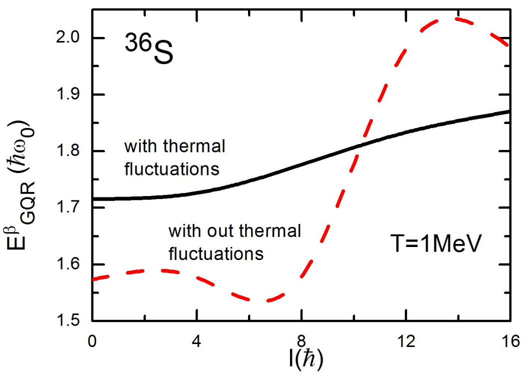

FIG. 2: The GQR beta mode energy values are shown at $T = 1$MeV, calculated with and without thermal fluctuations.

Results

Sample results in the case of ^{36}S are shown in Figs. 1 and 2. In Fig. 1 the variation of deformation as a function of spin is shown. The results with and without thermal fluctuations are shown at temperature 1 MeV. The deformation calculated without thermal fluctuations (most probable deformation) changes rapidly with spin whereas the deformation calculated with fluctuations (averaged) changes rather slowly. At lower spins the average deformation is finite though the nucleus is supposed to be spherical. This is due to the fact that at finite temperature the shapes corresponding to the states near lowest energy can also contribute to the deformation. All the dynamics of deformation is well reflected by the GQR energies as shown in Fig. 2. Here we have shown the energy of β-mode only. We can note that GQR energies are strongly modified in presence of thermal fluctuations.

In summary,a theoretical framework has been formulated to calculate the GQR energies for different isoscalar modes, in the presence of thermal fluctuation. Our results show that the GQR energies strongly reflect the shape transitions in hot and rotating nuclei despite the smoothing effect of thermal fluctuation.

References

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