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GIANT DIPOLE RESONANCE AND SHAPE FLUCTUATIONS IN RAPIDLY ROTATING HOT NUCLEI*

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In a macroscopic approach we study giant dipole resonance (GDR) in rapidly rotating hot nuclei. Thermal fluctuations in GDR observables are treated without employing free energy parametrizations. Analysis of their consequences at low temperature and high spin suggest that the parameterizations are not sufficient in this regime. We exemplify that at low temperature the sharp shape transitions due to increasing spin could be well reflected in the GDR observables once we treat the fluctuations properly. Jacobi transition in Zr isotopes leading to hyperdeformation and their survival at higher temperature are discussed.

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1. Introduction

Giant dipole resonance studies play vital role in understanding nuclear structure especially at finite angular momentum and temperature. Few experiments have been carried out recently to study the GDR states at low temperatures [1, 2]. At low temperatures microscopic effects (such as shell effects) are expected to be dominant and can overcome the thermal fluctuations. This may lead to survival of sharp structural transitions at higher spins. At the extreme limits of spin the occurrence of Jacobi transition (JT) is now well established through precise measurements [3]. JT could populate the hyperdeformed structures in some cases. In this work we study whether the shape transitions at low temperature are well reflected in GDR observables and as a special case we discuss JT at low T leading to hyperdeformation.

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2. Formalism

The details of theoretical formalism can be found in Refs. [4,5]. We follow a macroscopic approach in which the GDR observables are related to the nuclear shapes. For shape calculations we use the cranked Nilsson–Strutinsky method (CNSM) extended to high temperature [4]. When the nucleus is observed at finite excitation energy, the observables carry information on the relative time scales for shape rearrangements which lead to shape fluctuations. The general expression for the expectation value of an observable $\mathcal{O}$ incorporating both thermal and orientation fluctuations is given by [4–7]

$$\langle \mathcal{O} \rangle_{\beta,\gamma,\Omega} = \frac{\int \mathcal{D}[\alpha]\; e^{-F(T,I;\beta,\gamma,\Omega)/T} (\hat{\omega} \cdot \mathcal{I} \cdot \hat{\omega})^{-3/2} \mathcal{O}}{\int \mathcal{D}[\alpha]\; e^{-F(T,I;\beta,\gamma,\Omega)/T} (\hat{\omega} \cdot \mathcal{I} \cdot \hat{\omega})^{-3/2}}\,, \tag{1}$$

where $\Omega = (\phi, \theta, \psi)$ are the Euler angles specifying the intrinsic orientation of the system, $\hat{\omega} \cdot \mathcal{I} \cdot \hat{\omega}$ is the moment of inertia about the rotation axis $\hat{\omega}$, and the volume element $\mathcal{D}[\alpha] = \beta^4 |\sin 3\gamma|\, d\beta\, d\gamma\, \sin\theta\, d\theta\, d\phi$. Recently [4,5,8] few calculations have been done by performing the thermal fluctuation calculations by computing the integrations in Eq. (1) numerically with the free energies and the observables being calculated by CNSM at the integration (mesh) points. In this work we have performed such calculations, however, neglecting the orientation fluctuations which is reasonable while calculating the scalar observables [4, 9] such as the GDR cross section and width. For comparison, we employ Landau expansion in its extended form as given in Refs. [4, 10] to parameterize the free energy. This expansion carries the shell corrections evaluated at $\omega = 0$ all along to higher spins. This is not desirable as the shell corrections can change considerably with spin. The consequences of this at low temperature may be significant as we see from the following results.

3. Results and discussion

Our results for ^{147}Eu at $T = 1.3$ MeV and at $T = 0.5$ MeV are shown in Fig. 1 along with the experimental data. Our calculations reasonably agree with the experimental data and previous theoretical results [11]. In Fig. 1, we can see that at $T = 1.3$ MeV there is not much difference between the results of Landau theory and CNSM calculations. Also the widths are very much similar to those obtained using liquid drop model (LDM) as the proton and neutron shell corrections are weak and they act against themselves. This trend continues even at spins up to $60\,\hbar$. However, at

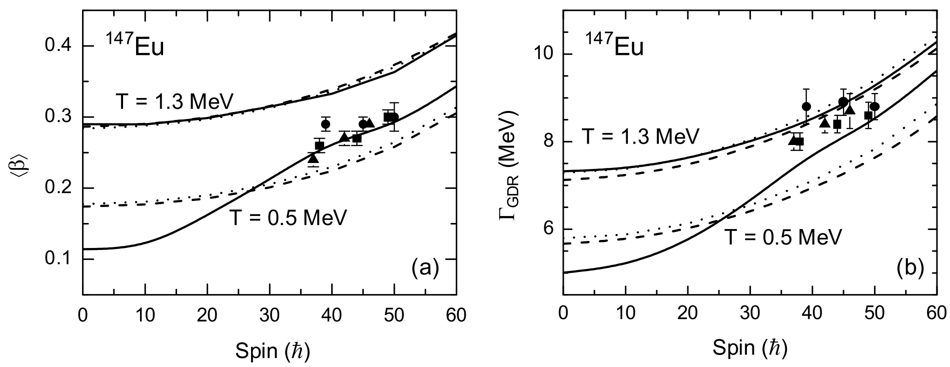

Fig. 1. Spin dependence of averaged shapes and GDR width in ^{147}Eu. The results obtained using LDM (dash-dotted line), Landau theory (dashed line) and the CNSM (solid line) are compared. The solid circle, solid square and solid triangle correspond to experimental data [11] at beam energies 170, 165 and 160 MeV respectively. These energies correspond to temperatures from 1.2 to 1.4 MeV [11].

$T = 0.5$ MeV, the results are substantially different as the spin-dependent shell-corrections play their role. At $\omega = 0$, the shell correction is of the order of 2 MeV and hence the three methods give different results. When the spin changes from $30\,\hbar$ to $40\,\hbar$, the equilibrium deformation β changes from 0.1 to 0.3 and at higher spins the local minimum at $\beta = 0.1$ vanishes which leads to extra increase in $\Gamma_{\rm GDR}$. These effects survive thermal fluctuations in the CNSM calculations and is averaged out in Landau theory and LDM calculations. Hence, it is clear that one cannot substantiate the success of Landau theory at moderate and high T. As exemplified in the case of ^{147}Eu the spin-dependent shell corrections can be crucial at low T.

Jacobi transition in ^{46}Ti could precisely be identified in a recent observation [3]. As we see in Fig. 2(a), our calculations could reasonably explain the data. Such observations are expected to be made in other regions also. It has been proposed [4] that in neutron-deficient Zr isotopes, shell corrections are stronger at high spins, favoring the JT leading to highly deformed shapes at lower T. In these isotopes the JT occurs at around 10 units of spin prior to the maximum sustainable spin [12]. Interestingly, in these cases JT at $T = 0$ leads to hyperdeformed states with $\beta \sim 0.9$. These states could survive thermal fluctuations at low temperatures [4]. In Fig. 2(b), we show the GDR cross-sections at $T = 1.0$ MeV. It is evident from Fig. 2(b) that, in certain nuclei at higher spin the free energy parameterizations could be inadequate even at $T \sim 1$ MeV. In the case of Zr isotopes our study suggests that the shell effects are vital enough at low T (~ 0.5 MeV) to overcome the thermal fluctuations and hence could still favor hyperdeformed states.

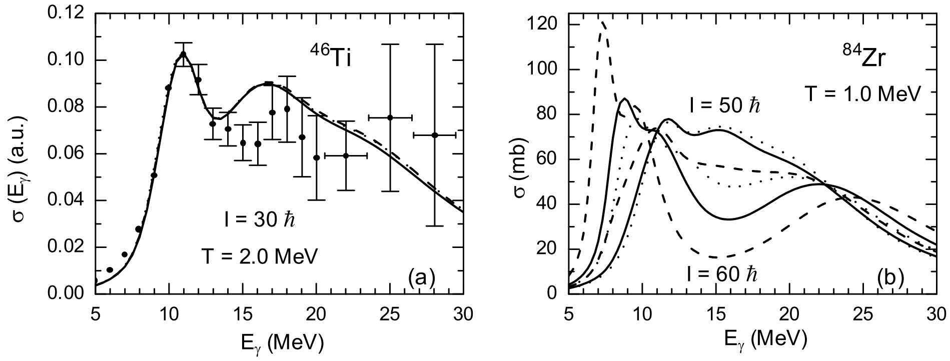

Fig. 2. GDR cross-sections at high spins for ^{46}Ti at $T = 2.0$ MeV and for ^{84}Zr at $T = 1.0$ MeV. Different lines have same meaning as in Fig. 1. In the left panel experimental data from Ref. [3] also are given.

4. Conclusions

The discrepancies in calculations using Landau theory in comparison with cranked Nilsson-Strutinsky calculations are shown in certain nuclei at moderate temperatures and high spin. This is ascribed to spin-dependent shell corrections, which the existing free energy parametrizations do not account for. With the proper inclusion of shell effects, we find the hyperdeformed structures in Zr isotopes to survive at low temperatures. In such cases GDR is expected to probe the hyperdeformation.

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