Effects of thermal shape fluctuations and pairing fluctuations on the giant dipole resonance in warm nuclei†

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The study of giant dipole resonance (GDR) at high temperature (T) and angular momentum (J) has been an interesting area of research, which has revealed several structural properties of nuclei at extreme conditions. Being a fundamental mode of photo excitation, GDR can probe nuclei at extreme conditions and even those with exotic structures. Since the nucleus is a tiny system, the thermal fluctuations inherent in finite systems are expected to be large. The shape degrees of freedom being crucial for nuclear structure, the deformation parameters are closely associated with the order parameters for the related transitions. Hence the thermal shape fluctuations (TSF) are the most dominant ones, and at low T the fluctuations in the pairing field can also contribute significantly. Many models have been used to study the effect of both these fluctuations separately, but the combined effect of these two was not investigated until our recent efforts.

In our recent work[1)], we have outlined some of our results from a theoretical approach for such warm nuclei where all these effects are incorporated along within the thermal shape fluctuation model (TSFM) extended to include the fluctuations in the pairing field. In this article, we present the complete formalism based on the microscopic-macroscopic approach for determining the deformation energies and a macroscopic approach which links the deformation to GDR observables. The TSFM built on Nilsson-Strutinsky calculations with a macroscopic approach to GDR was employed. The nuclear shapes are related to the GDR observables using the Hamiltonian written in terms of the dipole operator $\mathcal{D}$ and pairing operator P as $H = H_{osc} + \eta\, D^\dagger D + \chi\, P^\dagger P$, where H_{osc} stands for the anisotropic harmonic oscillator hamiltonian, the parameter η characterizes the isovector component of the neutron and proton average field and χ is the strength of the pairing interaction. The pairing interaction changes the oscillator frequencies $[\omega_\nu^{osc}(\nu = x, y, z)]$ to $\omega_\nu = \omega_\nu^{osc} - \chi\omega^P$, where $\omega^P = [(Z\Delta_P + N\Delta_N)/(Z+N)]^2$ with χ having the units of MeV^{-1}. Pairing renormalizes the dipole-dipole interaction strength to $\eta = \eta_0 - \chi_0\sqrt{T}\omega^P$, with χ_0 having the units of MeV$^{-5/2}$. The T-independent parameters η_0 and χ_0 are chosen to reproduce the GDR width at $T = 0$ and to obtain the overall agreement with the experimental widths at $T \neq 0$. The effective GDR cross-sections is calculated by averaging all the cross-sections $\sigma(E_\gamma, \beta, \gamma.\Delta_P, \Delta_N)$ obtained from thermal fluctuations of quadrupole shapes by using the formula for the expectation value of an observable $\mathcal{O}$ as $\langle\mathcal{O}\rangle_{\beta,\gamma,\Delta_P,\Delta_N} = \int \mathcal{O}W(T,\beta,\gamma,\Delta_P,\Delta_N)\mathcal{D}[\alpha] / \int W(T,\beta,\gamma,\Delta_P,\Delta_N)\mathcal{D}[\alpha]$ with $W(T,\beta,\gamma,\Delta_P,\Delta_N) = \exp[-F(T;\beta,\gamma,\Delta_P,\Delta_N)/T]$, $\mathcal{D}[\alpha] = \beta^4|\sin 3\gamma|\, d\beta\, d\gamma\, d\Delta_P\, d\Delta_N$. The total free energy (F_{TOT}) at a fixed deformation is calculated using the expression $F_{TOT} = E_{LDM} + \sum_{p,n}\delta F$. Each cross section $\sigma(E_\gamma, \beta, \gamma.\Delta_P, \Delta_N)$ is a sum of the Lorentzians, whose widths are given as $\Gamma_i = \Gamma_0(E_i/E_0)^\delta$ with Γ_0 and E_0 being the width and energy in the case of a spherical nucleus, respectively. The energy predicted by the liquid drop model (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.

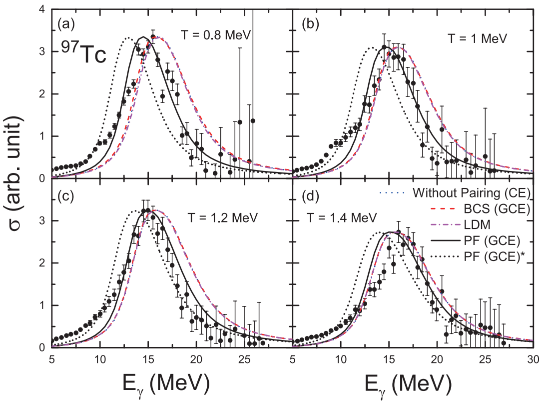

Fig. 1. The GDR strength functions for ^{97}Tc at different T are compared with the results obtained by using the pairing fluctuations (PF) within a grand canonical ensemble approach (GCE). Experimental data are shown by solid circles. The legend PF (GCE)* denotes that the calculations are with the parameter $\delta = 1.9$; in all other calculations $\delta = 1.8$.

We discussed our results for the nuclei ^{97}Tc, ^{120}Sn, ^{179}Au, and ^{208}Pb, and corroborated with the experimental data available. The TSFM could explain the data successfully at low temperature only with a proper treatment of pairing and its fluctuations (Fig. 1). More measurements with better precision could yield rich information about several phase transitions that can happen in warm nuclei.

Reference

1) A.K. Rhine Kumar, P. Arumugam, and N. Dinh Dang, Phys. Rev. C **90** (2014) 044308.

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