Pairing effect in thermal shape fluctuation model on the width of giant dipole resonance†

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The study of nuclear properties at high temperature, spin and isospin has gained much of interest in recent times. Apart from these extremes, there are still some unexplored regimes of hot nuclei. The properties of nuclei at very low temperatures and the phase transitions associated with that belong to such area where conclusive experimental results are scarce. At such low temperatures, the shell (quantal) and pairing effects are quite active though being modified by thermal effects. In hot nuclei, thermal fluctuations are expected to be large since the nucleus is a tiny finite system. Thermal shape fluctuations and fluctuations in the pairing field are the dominating fluctuations and have been so far studied separately within different models. Both of these fluctuations are expected to be present at low temperatures. However, the interplay between them has not been investigated so far. The present work addresses this subject and we study the influence of this interplay on the experimental observables, namely the width of giant dipole resonance (GDR). The thermal shape fluctuation model (TSFM), which is often used by experimentalists, describes the increase of the GDR width with temperature by averaging the GDR cross section over all the quadrupole shapes. However this model is known to largely overestimate the GDR width in open-shell nuclei at low temperatures. The success of a proper pairing approach[1,2] suggests the necessity of including pairing correlations to cure this shortcoming of the TSFM. This is done in the present work.

We employ the thermal shape fluctuation model built on Nilsson-Strutinsky calculations[3] with a macroscopic approach to GDR and examine the inclusion of the fluctuations in the pairing field. The nuclear shapes are related to the GDR observables using a model comprising an anisotropic harmonic oscillator potential with separable dipole-dipole interaction. In this formalism the GDR Hamiltonian can be written 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 denotes the strength of the pairing interaction. The pairing interaction changes the oscillator frequencies $[\omega_{\nu}^{osc}(\nu = x, y, z)]$ resulting in the new set of frequencies $\omega_{\nu} = \omega_{\nu}^{osc} - \chi\omega^{P}$, where $\omega^{P} = \left(\frac{Z\Delta_P + N\Delta_N}{Z+N}\right)^2$ with χ having the units of MeV^{-1}. Alternatively, the role of pairing is to renormalize the dipole-dipole interaction strength such that, $\eta = \eta_0 - \chi_0\sqrt{T}\omega^{P}$, with χ_0 having the units of MeV$^{-5/2}$. The effective GDR cross-sections is calculated by averaging all the cross-sections 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 $F_{TOT} = E_{LDM} + \sum_{p,n}\delta F$. The liquid-drop energy (E_{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 shell correction (δF) is obtained with exact temperature dependence using the single-particle energies given by the triaxial Nilsson model.

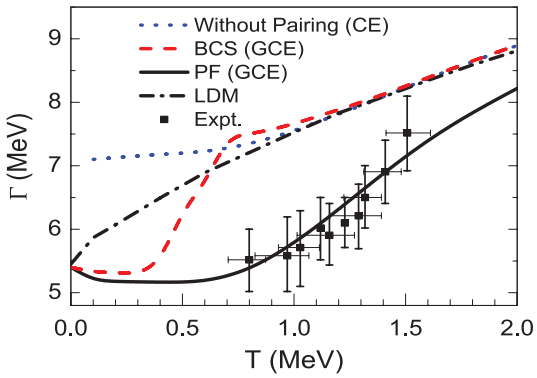

Fig. 1. (Color online) GDR width for ^{97}Tc, calculated within the liquid drop model (LDM), without pairing, including BCS pairing and pairing fluctuations, as a function of temperature in comparison with experimental data[2].

The results of our calculations for ^{97}Tc, ^{120}Sn and ^{208}Pb demonstrate that the TSFM can be quite successful if the shell effects (with explicit temperature dependence) and the pairing ones are properly incorporated in the free energy (See Fig. 1).

References
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