Giant dipole resonance in highly excited nuclei†

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The present work summarizes the achievements of the Phonon Damping Model (PDM)[1)] in the description of the the GDR width and shape at finite temperature T and angular momentum J. The GDR parameters predicted by the PDM and experimentally extracted are also used to calculate the shear viscosity of finite hot nuclei.

The PDM's Hamiltonian consists of the independent single-particle (quasiparticle) field, GDR phonon field, and the coupling between them. The Woods-Saxon potentials at $T = 0$ are used to obtain the single-particle energies ϵ_k. The GDR width $\Gamma(T)$ is a sum: $\Gamma(T) = \Gamma_{\rm Q} + \Gamma_{\rm T}$ of the quantal width, $\Gamma_{\rm Q}$, and thermal width, $\Gamma_{\rm T}$. In the presence of superfluid pairing, the quantal and thermal widths are $\Gamma_{\rm Q} = 2\gamma_Q(E_{GDR}) = 2\pi F_1^2 \sum_{ph} [u_{ph}^{(+)}]^2 (1 - n_p - n_h) \delta[E_{\rm GDR} - E_p - E_h]$, and $\Gamma_{\rm T} = 2\gamma_T(E_{GDR}) = 2\pi F_2^2 \sum_{s>s'} [v_{ss'}^{(-)}]^2 (n_{s'} - n_s) \delta[E_{\rm GDR} - E_s + E_{s'}]$, where $u_{ph}^{(+)} = u_p v_h + u_h v_p$, $v_{ss'}^{(-)} = u_s u_{s'} - v_s v_{s'}$ $(ss' = pp', hh')$ with the coefficients of Bogolyubov's transformation u_k and v_k, quasiparticle energies $E_k \equiv \sqrt{(\epsilon_k - \lambda)^2 + \Delta^2}$, superfluid pairing gap Δ, and quasiparticle occupations numbers $n_k = [\exp(E_k/T) + 1]^{-1}$. F_1 is chosen so that Γ_Q at $T = 0$ is equal to GDR's width at $T = 0$; F_2 is chosen so that, with varying T, the GDR energy E_{GDR} does not change significantly. E_{GDR} is the solution of $E_{GDR} - \omega_q - P_q(E_{GDR}) = 0$, where ω_q is the energy of the GDR phonon before the coupling between the phonon and single-particle mean fields is switched on, and $P_q(\omega)$ is the polarization operator owing to this coupling. In numerical calculations the representation $\delta(x) = \lim_{\varepsilon\to 0} \varepsilon/[\pi(x^2 + \varepsilon^2)]$ is used for the δ-function with $\epsilon = 0.5$ MeV.

In the verification of the condition for applying hydrodynamics to nuclear system, the quantum mechanical uncertainty principle requires a finite viscosity for any thermal fluid. It has been conjectured that the ratio η/s of shear viscosity η to the entropy volume density s is bounded at the lower end for all fluids, namely the value $\eta/s = \hbar/(4\pi k_B)$ is the universal lower bound (KSS bound or unit). From the viewpoint of collective theories, one of the fundamental explanations for the giant resonance damping is the friction term (or viscosity) of the neutron and proton fluids. The exact expression for the shear viscosity $\eta(T)$ in terms of the GDR's parameters at zero and finite T was obtained as $\eta(T) = \eta(0)[\Gamma(T)/\Gamma(0)]\{E_{GDR}(0)^2 + [\Gamma(0)/2]^2\}/\{E_{GDR}(T)^2 + [\Gamma(T)/2]^2\}$. The predictions

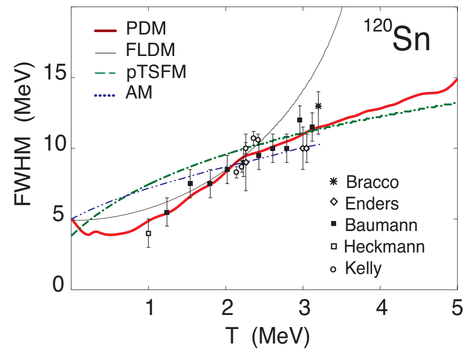

Fig. 1. GDR width for ^{120}Sn predicted by the PDM, phenomenological thermal shape fluctuations (pTSFM), adiabatic (AM), and Fermi liquid drop (FLDM) models as functions of T in comparison with experimental data in tin regions.

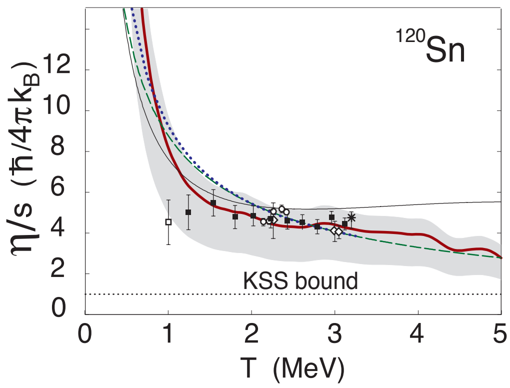

Fig. 2. The ratio η/s as a function of T for nuclei in the tin region. The gray areas are the PDM predictions by using $0.6u \le \eta(0) \le 1.2u$ with $u = 10^{-23}$ Mev s fm^{-3}.

for the GDR width and the ratio η/s by the PDM, pTSFM, AM, and FLDM for ^{120}Sn are plotted as functions of T in Figs. 1 and 2 in comparison with the empirical results. The latter are extracted from the experimental systematics for GDR in tin region making use this exact expression. It is seen that the predictions by the PDM have the best overall agreement with the empirical results. Based on these results and on a model-independent estimation, it is concluded that η/s for medium and heavy nuclei at $T = 5$ MeV is in between (1.3 - 4.0) KSS units.

References

1) N. Dinh Dang and A. Arima, Phys. Rev. Lett. **80**, 4145 (1998); Nucl. Phys. A **636**, 427 (1998); Phys. Rev. C **68**, 044303 (2003).

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