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COLLISIONAL DAMPING OF GIANT DIPOLE RESONANCE IN ^{120}Sn AND ^{208}Pb*

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We investigate the collisional damping of giant dipole resonance at finite temperature in the basis of a non-Markovian transport approach. We perform our calculations in Thomas–Fermi approximation by employing the microscopic in-medium cross-sections of Li and Machleidt and the phenomenological Gogny force. The results account for about 30% of the observed widths in ^{120}Sn and ^{208}Pb at finite temperatures.

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One of the possible processes contributing to the spreading width of giant dipole resonance (GDR) at finite temperatures is the damping due to coupling of the collective state with incoherent $2p$–$2h$ states which is usually referred to as the collisional damping [1–4]. We investigate the incoherent two-body collisions in the basis of a non-Markovian transport approach. In order to assess how much of the total width of GDR is exhausted by decay into incoherent $2p$–$2h$ states, we need realistic in-medium cross-sections which interpolate correctly between the free space and the medium. We employ the microscopic in-medium cross-sections of the Li and Machleidt [5] and perform our calculations in Thomas–Fermi approximation. For comparison, we also consider the phenomenological Gogny force and the Skyrme force [6, 7].

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We study the collective vibrations in the small amplitude limit of the extended TDHF theory in which damping due to incoherent $2p$–$2h$ decay is included in the form of a non-Markovian collision term [2]. In the Hartree–Fock representation, the Fourier transform of the self-energy is given by,

$$\Sigma_\lambda(\omega) = \frac{1}{4}\sum \frac{|\langle ij|[Q^\dagger_\lambda, v]|kl\rangle_A|^2}{\hbar\omega - \Delta\varepsilon + i\eta}[n_k n_l \bar{n}_i \bar{n}_j - n_i n_j \bar{n}_k \bar{n}_l]\,, \qquad (1)$$

where n_i denotes the finite temperature Fermi–Dirac occupation numbers of the Hartree–Fock states, $\bar{n}_i = 1 - n_i$, $\Delta\varepsilon = \varepsilon_i + \varepsilon_j - \varepsilon_k - \varepsilon_l$, $Q^\dagger_\lambda$ is the collective operator associated with RPA mode λ, and v is the effective interaction that couples the ph-space to the $2p$–$2h$ configurations. The real and imaginary parts of self-energy, $\Sigma_\lambda(\omega) = \Delta_\lambda(\omega) - \frac{i}{2}\Gamma_\lambda(\omega)$ determine the energy shift and the damping width of the collective excitation, respectively [8].

We consider the self energy in Thomas–Fermi approximation, which corresponds to a semi-classical transport description of the collective vibrations. In this approximation, $2p$–$2h$ self-energy can be deduced from the above quantal expression by replacing the occupation numbers with the equilibrium phase–space density given by the Fermi–Dirac function $n_i \to f(\varepsilon, T) = 1/[\exp(\varepsilon - \mu)/T + 1]$ with μ the chemical potential, and summations over the $2p$–$2h$ states with integrals over the phase-space $\Sigma \to \int d\boldsymbol{r}\, d\boldsymbol{p}_1 d\mathbf{p}_2 d\boldsymbol{p}_3 d\boldsymbol{p}_4$ [2, 9]. Furthermore, spin-isospin effects in the collective vibration can be incorporated into the treatment by considering proton and neutron degrees of freedom separately. Carrying out this semiclassical RPA treatment, we obtain for the collisional widths of isovector modes $\Gamma_\lambda = \int d\boldsymbol{r}\, \Gamma_\lambda(r)$ [2],

$$\begin{aligned}\Gamma_\lambda(r) \;=\; & \frac{1}{N_\lambda}\int d\boldsymbol{p}_1 d\boldsymbol{p}_2 d\boldsymbol{p}_3 d\boldsymbol{p}_4 [(W_{pp} + W_{nn})\left(\frac{\Delta\chi_\lambda}{2}\right)^2 \\ & + 2W_{pn}\left(\frac{\Delta\tilde{\chi}_\lambda}{2}\right)^2] Z f_1 f_2 \bar{f}_3 \bar{f}_4\,, \end{aligned} \qquad (2)$$

where $N_\lambda = \int d\boldsymbol{r}\, d\boldsymbol{p} (\chi_\lambda)^2[-(\partial/\partial\varepsilon)f]$ is a normalization, $\Delta\chi_\lambda = \chi_\lambda(1) + \chi_\lambda(2) - \chi_\lambda(3) - \chi_\lambda(4)$, $\Delta\tilde{\chi}_\lambda = \chi_\lambda(1) - \chi_\lambda(2) - \chi_\lambda(3) + \chi_\lambda(4)$, $Z = [\delta(\hbar\omega_\lambda - \Delta\varepsilon) - \delta(\hbar\omega_\lambda + \Delta\varepsilon)]/\hbar\omega_\lambda$, ω_λ is the mean-frequency of the RPA mode, and $\chi_\lambda(t)$ denotes the distortion factor of the phase-space density in the corresponding mode. In this expression, transition rates W_{pp}, W_{nn}, W_{pn} associated with proton-proton, neutron-neutron and proton–neutron collisions are given in terms of the corresponding scattering cross-sections as

$$W(12;34) = \frac{1}{(2\pi\hbar)^3}\frac{4\hbar}{m^2}\frac{d\sigma}{d\Omega}\delta(\boldsymbol{p}_1 + \boldsymbol{p}_2 - \boldsymbol{p}_3 - \boldsymbol{p}_4)\,. \qquad (3)$$

We use the formula (2) to calculate the collisional width of the GDR excitation by parametrizing the distortion factor of momentum distribution as $\chi_{\rm D} = pP_1(\cos\theta)$. Because of momentum conservation, terms involving W_{pp} and W_{nn} drop out, and the damping is determined by the proton–neutron collision term. The spin averaged proton–neutron cross-section associated with an effective residual interaction can be expressed as

$$\left(\frac{d\sigma}{d\Omega}\right)_{pn} = \frac{\pi}{(2\pi\hbar)^3}\frac{m^2}{4\hbar}\frac{1}{8}\sum_{ST}(2S+1)|\langle \boldsymbol{q};S,T|v|\boldsymbol{q}';S,T\rangle_A|^2\,, \tag{4}$$

where $\boldsymbol{q}$ and $\boldsymbol{q}'$ are the relative momenta before and after a binary collision, and $\langle \boldsymbol{q};S,T|v|\boldsymbol{q}';S,T\rangle_A$ represents the fully anti-symmetric matrix element of the residual interaction between two particle states with total spin and isospin S and T.

We calculate proton–neutron cross-section associated with the Gogny force and the Skyrme force with SkM* parameters [10], and compare them with the microscopic in-medium cross-section of Li and Machleidt. In Fig. 1 the cross-sections are plotted as a function of density at the bombarding energy $E_{\rm lab} = 100$ MeV which is equal to twice the energy available in the centre of mass. For decreasing density, the microscopic calculation approach the free proton–neutron cross-section and compare well with the experimental data, whereas the phenomenological cross-sections strongly increase and reach large values in free space, therefore we can state that the microscopic calculations of Li and Machleidt provide a more reliable description of the in-medium cross-sections than those given by the Gogny and the Skyrme type forces.

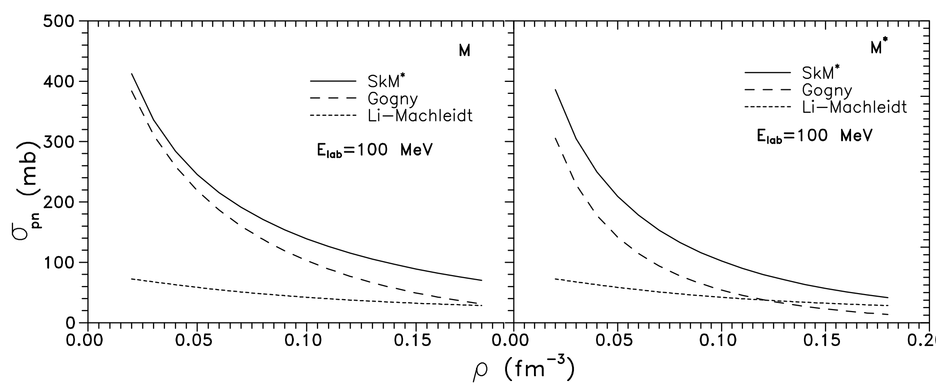

Fig. 1. The proton–neutron in-medium cross-sections as a function of density ρ at $E_{\rm lab} = 100$ MeV.

We evaluate the integrals in the expression (2) for the damping width of GDR exactly by neglecting the angular anisotropy of the cross-sections and making the replacement $(d\sigma/d\Omega)_{pn} \to \sigma_{pn}/4\pi$ [10]. In numerical calculations, we determine the nuclear density $\rho(r)$ in Thomas–Fermi approximation using a Wood–Saxon potential with a depth $V_0 = -44$ MeV, thickness $a = 0.67$ fm and sharp radius $R_0 = 1.27A^{1/3}$ fm, calculate the position dependent chemical potential $\mu(\varepsilon, T)$ in the Fermi–Dirac function $f(\varepsilon, T)$ at each temperature, and use the formula $\hbar\omega = 80A^{-1/3}$ for GDR energies.

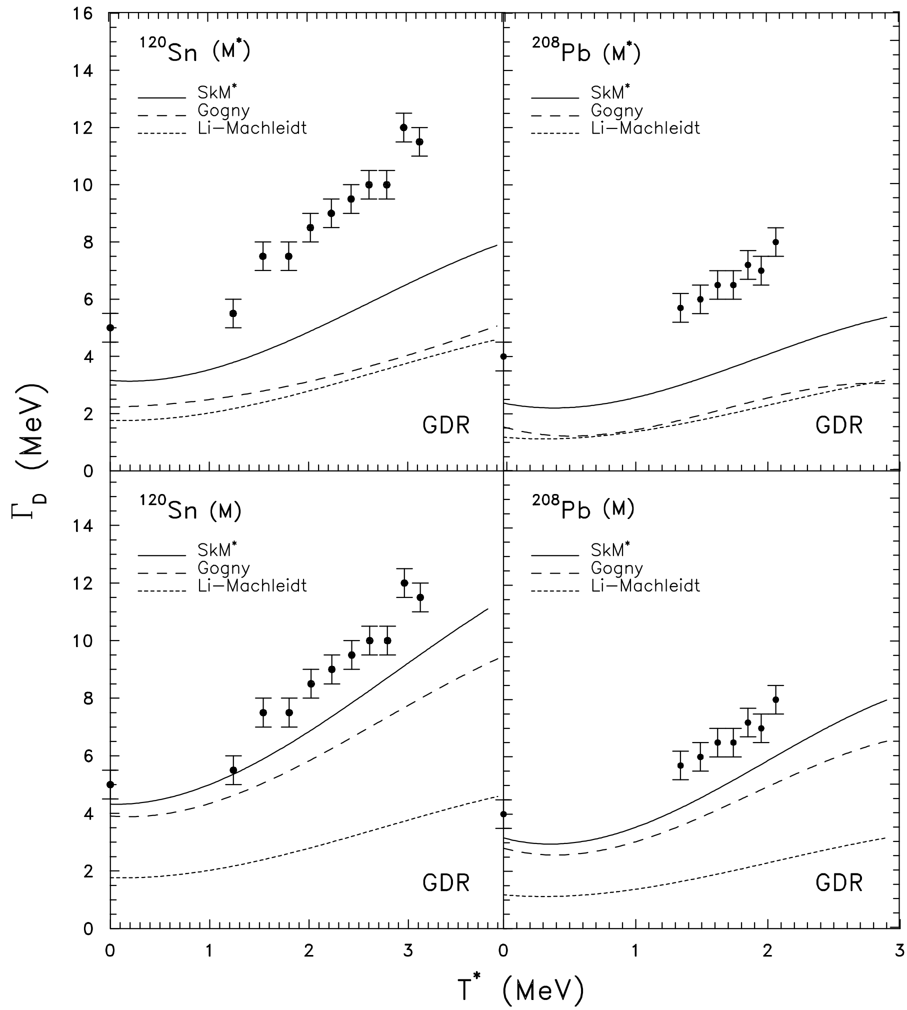

Fig. 2. The collisional damping width of GDR in ^{120}Sn and ^{208}Pb as a function of temperature.

Fig. 2 shows the collisional damping width of GDR in ^{120}Sn and ^{208}Pb as a function of the experimental temperature and comparison with data [11]. The calculations with cross-sections of Li and Machleidt exhibit a weaker temperature dependence than data and account for about 30% of the experimental damping widths. Since phenomenological cross-sections do not interpolate correctly between the free space and the medium, their magnitude at low densities and in the vicinity of Fermi energy, where the dominant contributions to damping arise, become much larger than the cross-sections of Li and Machleidt. As a result, the phenomenological forces predict larger damping, although the magnitude of the damping is reduced by the effective mass.

Therefore, to the extend that we accept the validity of the in-medium cross-sections of Li and Machleidt, we can conclude that the collisional damping of GDR excitations is not very strong and accounts for about 1/3 of the spreading width in tin and lead nuclei at zero and finite temperatures.

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