Effects of one and two-body relaxations on isoscalar compression modes

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We study [1] the sensitivities of the centroid energy *E0* of the isoscalar giant monopole resonance (ISGMR) and the centroid energy *E1* of the isoscalar giant dipole resonance (ISGDR) to the effect of relaxation. We use the semi-classical kinetic approach in $(\boldsymbol{r},\boldsymbol{p})$ phase space, also called the fluid dynamic approach (FDA). A small variation of the distribution function $\delta f(\boldsymbol{r},\boldsymbol{p})$ can be evaluated using the linearized kinetic equation. To evaluate δf we will apply the linearized Landau-Vlasov equation, augmented by a source term $\delta St(f)$ for relaxation processes, in the form

$$\frac{\partial}{\partial t}\delta f + \mathbf{v}\cdot\nabla_{\mathbf{r}}\delta f - \nabla_{\mathbf{r}}\left(\delta U_{\text{self}} + U_{\text{ext}}\right)\cdot\nabla_{\mathbf{p}} f_{\text{eq}} = \delta St\left[f\right], \qquad (1)$$

where $\boldsymbol{v} = \boldsymbol{p}/m^*$ is the quasi-particle velocity and m^* is the effective mass of the nucleon. U_{self} and U_{ext} are the mean field and external field, respectively. The right-hand side of Eq. (1) represents the change of the distribution function due to relaxation. In this work we use the approximation

$$\delta St\left[f\right] = -\frac{\delta f}{\tau_{\text{eff}}}, \qquad \frac{1}{\tau_{\text{eff}}} = \frac{1}{\tau_2} + \frac{1}{\tau_1} + \frac{1}{\tau_\uparrow}. \qquad (2)$$

Here, the term $1/\tau_2$ is due to the two-body collisions on the distorted Fermi surface, $1/\tau_1$ determines the change in the distribution function resulting from one-body relaxation on the moving nuclear surface and $1/\tau_\uparrow$ takes into account the possibility of particle emission. We assume

$$\tau_2 = \frac{\hbar\beta}{\left(\hbar\omega_R/2\pi\right)^2}, \qquad \tau_1 = \frac{2R_0}{\bar{v}}\xi. \qquad (3)$$

In Eq. (3) ω_R is the real part of the eigenfrequency of the sound mode. The coefficient β depends on the *NN*-scattering cross sections. We will use the value of β=4.6 MeV which corresponds to the isotropic energy independent *NN*-cross sections $\sigma_{pp} = \sigma_{nn} = 25$ mb and $\sigma_{pn} = \sigma_{np} = 50$ mb. R_0 is a nuclear radius, $\bar{v} = 3v_F/4\ v$ and ζ is a free numerical factor which depends on the excitation mode. For heavy nuclei, the value of the emission width $\Gamma_\uparrow \approx 1/\tau_\uparrow$ is quite small and we neglect the contribution of the particle emission to the total relaxation time τ_{eff}. Evaluating the $\boldsymbol{p}$-moments to the kinetic equation (1), one can reduce the kinetic equation to the equation for the particle density eigenvibrations, $\delta\rho_L$, depending on momenta q and frequencies ω. Imposing the boundary conditions for the consistent solutions of both the continuity and the Euler equations, taken at the moving nuclear surface, one obtains a solution for $\delta\rho_L(q,\omega)$ by solving a dispersion relation for $\omega = E + i\Gamma$ and a secular equation for q.

In the figure below, we show the dependence of the energy ratio *E1/E0* on the nuclear mass number *A*. Considering the dependence of the FDA ratio $(E1/E0)_{FDA}$ on the relaxation time τ_{eff}, we find a good agreement between experimental data and the results of the FDA model calculations (solid line 2) for the value of ζ fitted to the widths Γ0 and Γ1. In the figure, the ratio $(E1/E0)_{FDA}$ for the rare collision regime (solid line 1) was obtained for the limit $\tau_{eff} \rightarrow \infty$, and $(E1/E0)_{RPA}$ is obtained from quantum and fully self-consistent Hartree-Fock based Random Phase Approximation (HF-RPA) calculations. The ratio $(E1/E0)_{scaling}$ (dotted line) is obtained from the scaling model. Also shown is the liquid drop (LDM) limit of ≈ 1.43. The ratios $(E1/E0)_{RPA}$, $(E1/E0)_{scaling}$ and $(E1/E0)_{FDA}$ in a rare collision regime significantly exceed the liquid drop model (LDM) estimate $(E1/E0)_{LDM}$ and the experimental data $(E1/E0)_{exp}$=1.6±0.1 [2, 3].

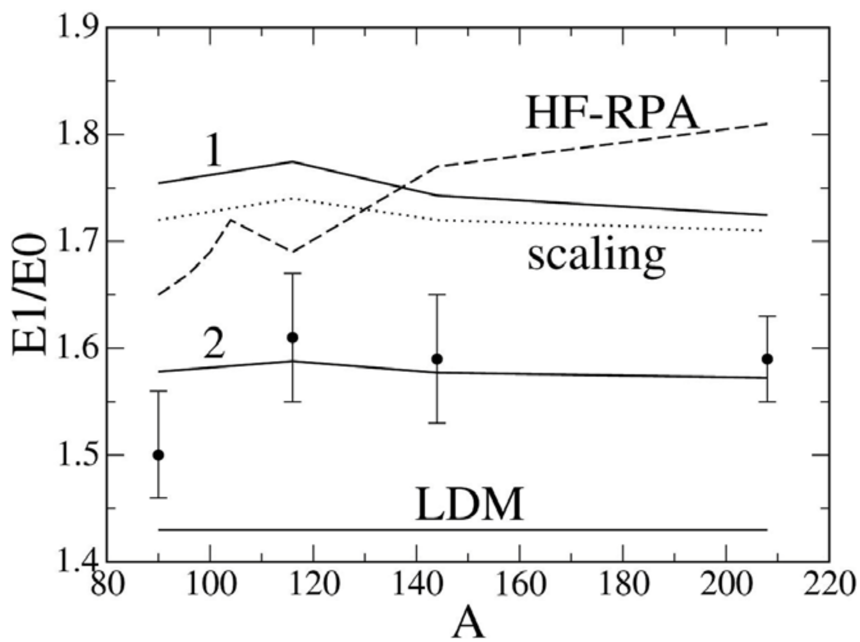

FIG. 1. Dependence of the energy ratio *E1/E0* on the nuclear mass number *A*.

We have demonstrated that one can obtain an agreement with the experimental data on *E1/E0* in the presence of relaxation processes. Besides the collisional width, the experimentally observable widths of the ISGMR and the ISGDR include the fragmentation width. Within our semi-classical kinetic theory, this mechanism of resonance spreading is considered an additional relaxation effect (one-body relaxation) due to the single particle scattering on the moving surface of the nucleus [3].

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[3] D.H. Youngblood, H.L. Clark and Y.-W. Lui, Phys. Rev. C **69**, 054312 (2004).