

Damping effects on centroid energies of isoscalar compression modes

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Experimental data for the centroid energies $E1$ of the isoscalar giant dipole resonance (ISGDR) are significantly smaller than those obtained by the self-consistent Hartree Fock (HF) random phase approximation (RPA) calculations with effective interactions, which reproduce the experimental value of the centroid energy $E0$ of the isoscalar giant monopole resonance (ISGMR). The experimental value $(E1/E0)_{\text{exp}} = 1.60 \pm 0.1$ exceeds the prediction of the liquid drop (hydrodynamic) model (LDM) and lies below the theoretical results for the ratio $E1/E0$ obtained in both the RPA and the scaling-like calculations. In this work we study the sensitivity of $E0$ of the ISGMR and $E1$ of the ISGDR to the effect of relaxation (collisional damping). We use the semiclassical kinetic approach in phase space. This approach, in contrast to the quantum Hartree-Fock based RPA, ignores the single particle (shell) effects. However, the advantage is that the kinetic theory allows one to take into consideration the relaxation (damping) processes in a transparent way via the collisional integral.

We start from the fluid dynamic equations of motion for the viscous Fermi liquid. Within the fluid dynamic approach (FDA) [1], the eigenfrequency ω of the compression eigenmodes satisfies the dispersion equation

$$\omega^2 - c_0^2(\omega)q^2 + i\omega\gamma(\omega)q^2 = 0, \quad c_0^2(\omega) = [K + 12\mu(\omega)/\rho_0]/9m, \quad \gamma(\omega) = 4\nu(\omega)/3\rho_0m, \quad (1)$$

where K is the incompressibility coefficient, ρ_0 is the bulk particle density and m is the nucleon mass. The transport coefficients $\mu(\omega)$ and $\nu(\omega)$ in Eq. (1) are due to the Fermi distortion effects [1] and depend on the relaxation time τ . The wave number q in Eq. (1) is due to the boundary conditions on the free surface of the nucleus, which are significantly different for the ISGMR and the ISGDR because the ISGDR appears as the overtone to the spurious mode. We have carried out calculations for the isoscalar monopole and dipole giant resonances in the frameworks of Hartree-Fock based RPA and the semiclassical Fermi liquid approach. We have solved the dispersion Eq. (1) augmented by the corresponding boundary condition for both ISGMR and ISGDR for several nuclei. Since the ISGDR appears as the overtone to the spurious mode, the energy of the ISGDR is shifted to higher energies with respect to the liquid drop model (LDM) prediction because of the Fermi surface distortion effect and it is sensitive to the interparticle collisions. As a result, the energy ratio $E1/E0$ decreases and approaches the experimental value if the collisional damping is taken into account.

We find [2] that the ratio $(E1/E0)_{\text{FDA}}$ depends on the relaxation time $\tau = \hbar\beta/(\hbar\omega/2\pi)^2$ and approaches the experimental value $(E1/E0)_{\text{exp}} = 1.60 \pm 0.1$ in a short relaxation time limit at $\beta = 0.75$. In rare collision regime ($\omega\tau \gg 1$), the compression mode energies $E0$ and $E1$ are saturated at certain values which correspond to the zero sound velocity $c_0 = [K + (24/5)\epsilon_F/9m]^{1/2}$ (ϵ_F is the Fermi energy). In frequent collision regime ($\omega\tau \ll 1$, small β), the contribution to the sound velocity c_0 from the Fermi surface distortion effect is washed out and both energies $E0$ and $E1$ reach the first sound limit (i.e., the LDM

regime) at $c_0 = c_1 = (K/9m)^{1/2}$. We note also the non-monotonic behavior of the widths Γ_0 and Γ_1 for the ISGMR and the ISGDR, respectively, which is a consequence of the memory effect (ω -dependence) in the friction coefficient $\gamma(\omega)$ of Eq. (1).

[1] V. M. Kolomietz and S. Shlomo, Phys. Rev. C **61**, 064302 (2000).

[2] D. C. Fuls, V. M. Kolomietz, S. V. Lukyanov, and S. Shlomo, to be published.