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Collisionless damping of isoscalar giant resonances in heavy nuclei

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The collisionless damping of collective excitations in finite Fermi systems has the same origin as the collisionless Landau damping for zero sound in an infinite Fermi system, and can also be produced by the interaction of nucleons with the dynamic nuclear surface (the one-body damping). In a self-consistent model, it can be expected that there is a coupling between these damping mechanisms. In this paper, the nature of the collisionless damping of isoscalar giant resonances in heavy nuclei is studied by using a kinetic model based on the linearized Vlasov equation for finite Fermi systems with a free moving surface [1]. This model includes the Landau damping mechanism as well as the one-body one. Indeed, the study of the surface response of a semi-infinite Fermi system in the same kinetic model revealed a damped surface mode whose friction coefficient is described by the wall formula [2]. Therefore, we can assume that the damping effects due to one-body friction are also present in the model for a finite Fermi system. We consider the collisionless damping of the giant quadrupole and high-energy octupole resonances, which are observed in heavy nuclei.
In our model, the isoscalar multipole strength function $S_L(E)$ that determines collective excitations in nuclei can be written in the form:
$\mathrm{S}_L(E) = S^L_{stat}(E) + S^L_{surf}(E)$,
$tag1where$E = $\hbar\omega$ is the excitation energy. The strength function for a system with a fixed (static) surface $S^L_{stat}(E)$ is: $\mathrm{S}^L_{stat}(E) = -\frac{1}{\pi}\mathrm{Im}\frac{R^0_L(E)}{1-\kappa_L R^0_L(E)}$.
$tag2Here$,$\mathrm{R}^0_L(E)$ is the zero-order response function, giving the strength distribution over multipole single-particle modes, which form a continuum from zero to infinity for multipolarity $L > 1$. The parameter k_L determines the strength of the isoscalar residual interaction between nucleons of multipolarity L, with a separable form: $\mathrm{V}_L(r,r') = \kappa_L \sum_M r^L r'^L Y_{LM}(\theta,\varphi)\, Y^*_{LM}(\theta',\varphi')$,
$tag3where$r=(r,θ,φ) is the radius-vector of a nucleon, and $Y_{LM}(\theta,\varphi)$ are the spherical harmonics. It can be seen in Figs. 1(a), 1(b) and 1(c) that the giant quadrupole resonance is formed in a Fermi system with a fixed surface due to the residual interaction between nucleons. In the fixed-surface model, the resonance width, which is produced by the Landau damping mechanism, is sensitive to the strength parameter k. The high-energy octupole resonance exhibits similar properties. The function $S^L_{surf}(E)$ describes the effect of moving surface on isoscalar resonances, which also includes damping effects created by the one-body damping mechanism. The main effect is a change in the width of the giant quadrupole resonance and the high-energy octupole resonance, compare the solid curves in Fig. 1(d), 1(e) and 1(f) with the solid curves in Fig. 1(a), 1(b) and 1(c).The width of the giant quadrupole and high-energy octupole resonances of a finite Fermi system are reduced in the moving-surface model, when both the Landau and one-body damping mechanisms are included, compare the solid curves with the dashed ones in Fig.2 (see the figures Fig.1 and Fig.2 in the attached materials).

Fig. 1. Isoscalar quadrupole strength functions in fixed- and moving-surface models. In Figs. 1(a), 1(b), 1(c), the solid curves show the fixed-surface strength functions for different value of the strength parameter k, while the dashed curves are for $k = 0$. In Figs. 1(d), 1(e), 1(f), the solid curves show the moving-surface strength functions for different value of the strength parameter k, while the dashed curves are for $k = 0$. The strength parameters k are chosen as $k = 0.85k_2$ in Figs. 1(a), 1(d), $k = k_2$ in Figs. 1(b), 1(e), and $k = 1.1k_2$ in Figs. 1(c), 1(f), where k_2=-1$\cdot10^{-3}$ MeV/fm^4. The system contains $A = 208$ nucleons.

*Fig. 2. Isoscalar quadrupole, Figs. 2(a), 2(b), and octupole, Figs. 2(c), 2(d), strength functions in moving-surface (solid curves) and fixed-surface (dashed curves) models. The system contains A=208 and A=90 nucleons.The strength parameters k are chosen as k_2(208)=-1$\cdot10^{-3}$ MeV/fm^4 in Fig. 2(a), k_2(90)=-7$\cdot10^{-3}$ MeV/fm^4 in Fig. 2(b), for the quadrupole strength functions and k_3(208)=-2$\cdot10^{-5}$ MeV/fm^6 in Fig. 2(c), k_3(90)=-2.5$\cdot10^{-4}$

MeV/fm^6 in Fig. 2(d), for the octupole ones. The experimental centroid energies of giant quadrupole and high-energy octupole resonances for ^{208}Pb and ^{90}Zr are indicated by arrows.*

In this paper, it is shown that an interplay between the Landau damping and the one-body one leads to a noticeable decrease in the width of the giant quadrupole and high-energy octupole isoscalar resonances in heavy nuclei. The found collisionless damping of the giant quadrupole and high-energy octupole resonances is too weak to describe the observed widths of these isoscalar resonances in heavy nuclei. It is necessary to involve other sources of damping, in particular the collisional damping mechanism, which can be consistently included in the present kinetic model.

References

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