Investigation of the energy-averaged double transition density of isoscalar monopole excitations in medium-heavy mass spherical nuclei

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The study of properties of collective states in nuclei provides information on the bulk properties of nuclear matter. In particular, the interest in experimental and theoretical studies of high-energy particle-hole-type isoscalar monopole (ISM) excitations in medium-heavy mass nuclei is mainly due to the possibility of determining the nuclear matter incompressibility coefficient, a fundamental physical quantity essential for astrophysics and nuclear physics. The value of this coefficient depends on the mean energy of the strength distribution of the isoscalar giant monopole resonance (ISGMR), corresponding to the ISM external field $r^2 Y_{00}$. To deduce this strength distribution from experimental data of (α,α')-inelastic scattering cross sections at small angles, it is usually assumed that the ISM strength is concentrated in the vicinity of the ISGMR and the properly normalized classical collective model transition density of the ISGMR can be used within the folding model distorted wave Born approximation (FM-DWBA). It is important to point out that the classical collective model one-body transition density is independent of the excitation energy.

We emphasize that in a microscopic approach, the input quantity for the analysis of the (α,α')-reaction cross section should be the energy-averaged double transition density (i.e. the energy-averaged product of energy dependent transition densities taken in different points). In a wide excitation-energy interval involving the ISGMR and its overtone, ISGMR2, this quantity is expected to be different from the product of the classical collective model transition densities, which is independent of excitation energy, or the product of microscopic transition densities, due to proper treatment of the shell structure of nuclei (i.e. the Landau damping) and also the spreading effect. In this work we apply the newly developed particle-hole dispersive optical model (PHDOM) to study properties of high-energy isoscalar monopole excitations in ^{208}Pb. The PHDOM, as an extension of the continuum-RPA, accounts for the Landau damping, coupling of high-energy (p-h)-type states to the single-particle (s-p) continuum and to many-quasiparticle configurations (the spreading effect). The PHDOM allows one to describe the energy-averaged ISM double transition density at arbitrary (but high-enough) excitation energy and, in particular, to trace the change of this quantity from the ISGMR to ISGMR2.

In this work[1] we have carried out an investigation of the energy-averaged double transition density. The calculations were performed for ISM excitations in ^{208}Pb. A wide excitation-energy interval is considered which includes the ISGMR and ISGMR2. The fractions of the energy-weighted sum-rule (EWSR) associated with the strength functions of these resonances, i.e. the energy-weighted strength functions divided by the corresponding EWSR, were analyzed. We also considered single p-h transition density obtained by various projections of the double p-h transition density, as well as the classical collective models transition densities, and investigate their applicability. This is done by considering the excitation cross sections with the Born approximation and comparing with the results obtained from the double p-h transition density. We add that it is important to carry out this test on the accuracy of the experimental analysis of cross sections before a reliable comparison between experimental data with theoretical prediction obtained using energy density functional.

To describe the properties of the ISGMR and ISGMR2, it is convenient to choose for the radial external fields the forms

$$V_{0,1}(r) = r^2 \, and \, V_{0,2}(r) = r^4 \qquad r^2, \tag{1}$$

respectively. To study possibilities of an appropriate factorization of the ISM double-transition-density radial dependence in a wide excitation-energy interval, we define the projected transition density,

$$_{V_0}(r, \quad) = \qquad (r,r', \quad)V_0(r')dr' \Big/ S_{V_0}^{1/2}(\quad) \,, \tag{2}$$

which can be considered as the transition density of a given ISM giant resonance (ISGMR or the ISGMR2). This transition density, which is energy-dependent, of the corresponding giant resonance, fulfils the condition that the strength function is obtained by

$$S_{V_0}(\quad) = \Big(\qquad _{V_0}(r, \quad)V_0(r)dr \Big)^2 . \tag{3}$$

In the experimental analysis of inelastic (α,α')-scattering cross sections at small angles the folding model (FM)-DWBA is usually employed. One first determines the optical potential by folding a Fermi distribution for the ground state matter density with a parameterized α-nucleon interaction, determined by a fit to the elastic scattering cross-section. Next, the classical collective ISGMR and ISGMR2 transition densities are folded with the α-nucleon interaction to determine the transition potentials. Then the optical potential and the transition potentials are used as input for the DWBA code. Since only the energy-averaged ISM double transition density can be obtained within the PHDOM, we study the accuracy of this approach by calculating the excitation cross section within the Born approximation. In this approximation, the energy averaged transition strength function is proportional to the strength function $S_{V_{0,q}}$, corresponding to the external field $V_{0,q}(r) = \frac{\sin(qr)}{qr}$. We have considered the energy-averaged strength function $S_{V_{0,q}}(\quad)$, which determines in the Born approximation the excitation cross-section of the ISGMR and its overtone in ^{208}Pb by 240 MeV α-particle scattering. In Figs. 1 and 2 we show the strength function evaluated via energy-averaged microscopic double transition density $\quad(r, r', \quad)$ in comparison with the strength functions evaluated with the use of the factorized projected and properly normalized classical transition densities, $_i(r, \quad)$ and $_{c,i}(r, \quad)$. As follows from this comparison, the description with the use of the factorized projected transition densities reproduces satisfactorily the "exact" description in a vicinity of the ISGMR (i=1) and ISGMR2 (i=2).

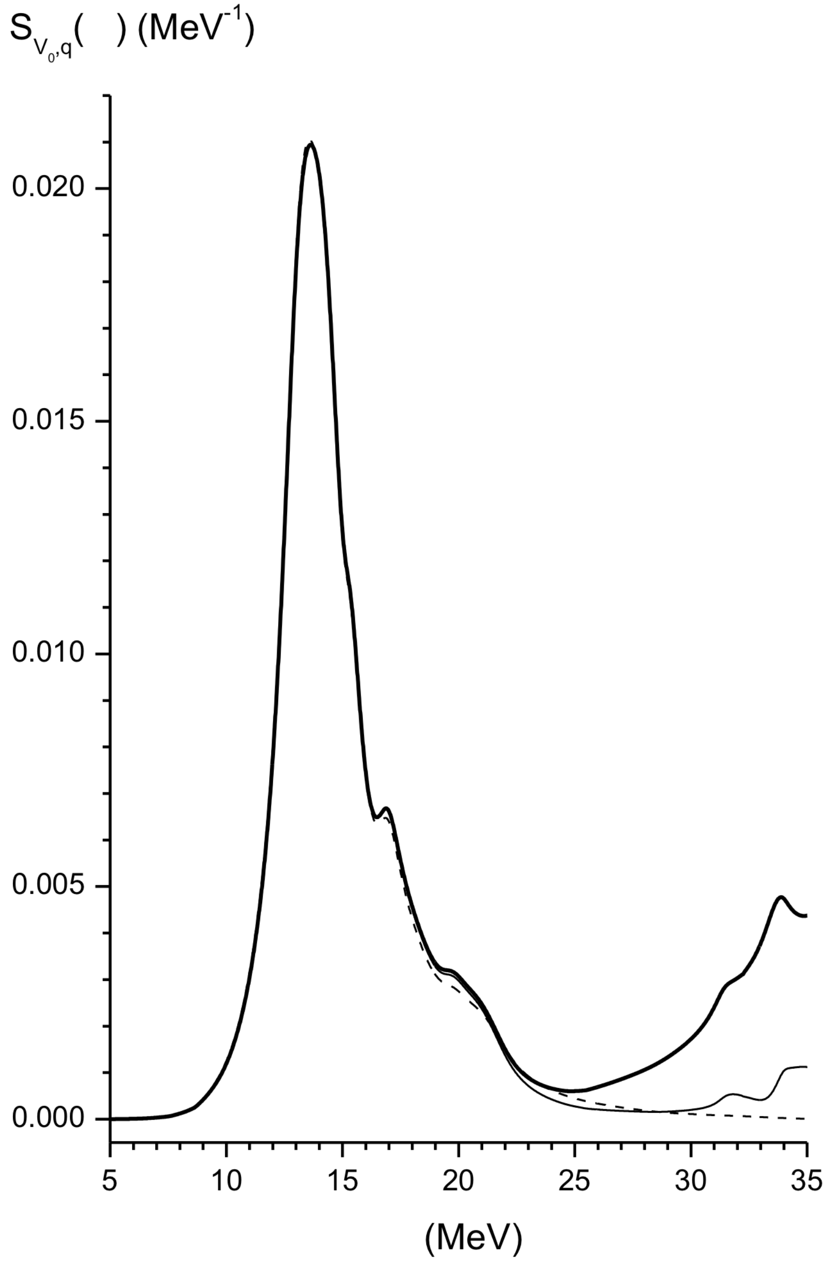

FIG. 1. The strength function $S_{V_{0,q}}(\ )$ shown (the solid thick line) in a comparison with the strength function, corresponding to the same external field but calculated with the use of the projected double transition densities $_{i}(r,r',\ )$ (the solid thin red line) and the properly normalized classical double transition densities $_{c,i}(r,r',\ )$ (the dashed blue line) for the ISGMR (i=1)

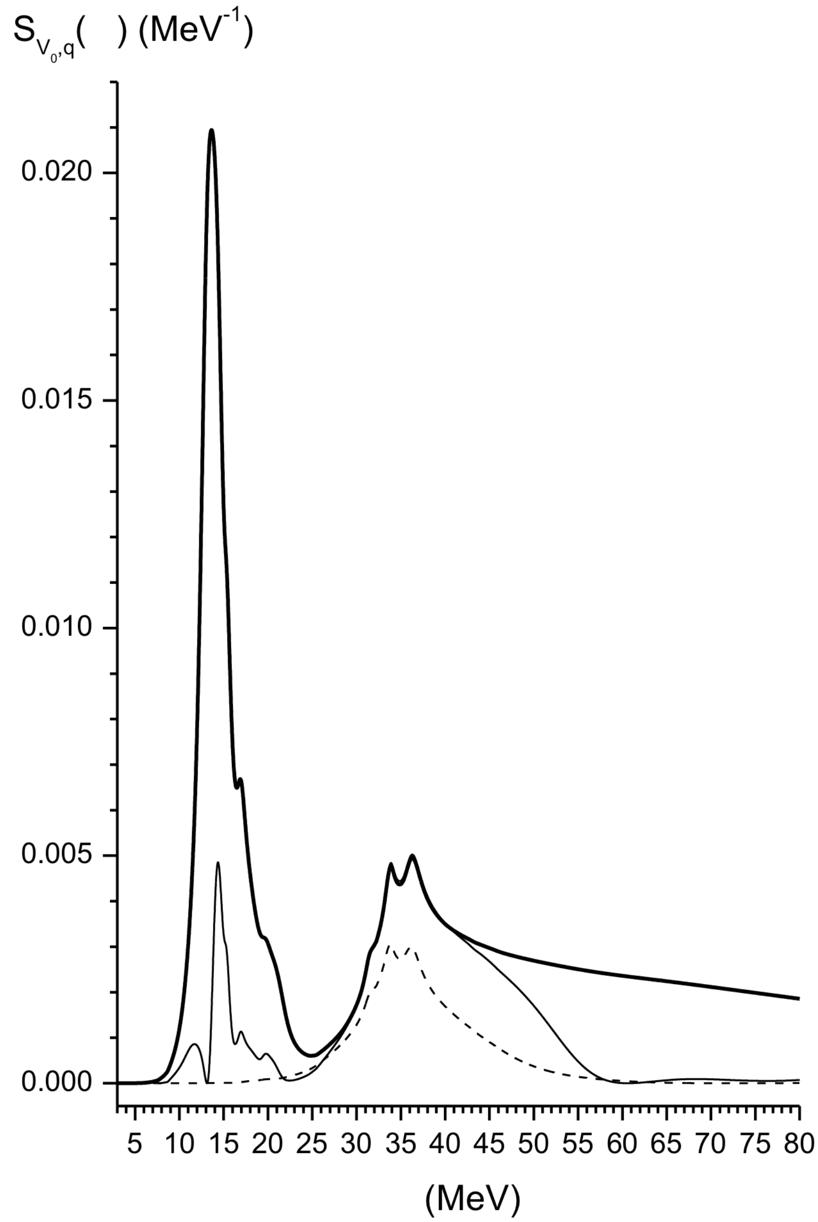

FIG. 2. Same as Fig. 1 but for the ISGMR2 (i=2).

[1] M.L. Gorelik, S. Shlomo, B.A. Tulupov, and M.H. Urin, Nucl. Phys. **A** (to be published).