EFFECTS OF PHONON–PHONON COUPLING ON PROPERTIES OF PYGMY RESONANCE IN ^{132}Sn*

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Starting from an effective Skyrme interaction, we study the effects of phonon–phonon coupling on the low-energy spectrum of the 1^- states in ^{132}Sn. The calculations are performed within a finite rank separable approximation for the particle-hole interaction. The inclusion of two-phonon configurations brings a sizeable contribution to the low-lying strength. Comparison with available experimental data shows a reasonable agreement for the low-energy E1 strength distribution.

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1. Introduction

The electric dipole (E1) response of nuclei at energies around the particle separation energy is presently attracting much attention, particularly for unstable neutron-rich nuclei produced at radioactive beams [1]. The structure and dynamics of the low-energy dipole strength, also referred to as pygmy dipole resonance (PDR), has extensively been investigated using a variety of theoretical approaches and models [2]. In addition, the study of the pygmy E1-strength is expected to provide information on the neutron skin and the symmetry energy term of the nuclear equation of state. This information is very relevant for the modeling of neutron stars. One of the successful tools for describing the PDR is the quasiparticle random phase approximation (QRPA) with the self-consistent mean-field and the residual

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interaction derived from Skyrme energy density functionals (EDF). Due to the anharmonicity of vibrations, there is a coupling between one-phonon and more complex states [3]. The main difficulty is that the complexity of calculations beyond standard QRPA increases rapidly with the size of the configuration space, so that one has to work within limited spaces. Using a finite rank separable approximation [4–6] for the residual interaction resulting from Skyrme forces, one can overcome this difficulty. In this paper, we study the properties of the low-lying and high-lying electric dipole strength in the doubly magic nucleus ^{132}Sn. The effects of the couplings between one- and two-phonon components in the wave functions of excited states are studied.

2. Details of calculations and results

The calculations are performed by using the SLy4 [7] EDF in the particle-hole channel and a density-dependent zero-range interaction in the particle–particle channel. This parametrization was proposed to describe isotopic properties of nuclei from the β^--stability line to the drip lines. Using such an EDF, we can reproduce very well experimental data for the low-lying 2^+ states and the properties of giant resonances [5, 6, 8, 9].

We take into account the coupling between the one- and two-phonon components in the wave functions of the excited states [3]

$$\Psi_\nu(\lambda\mu) = \left(\sum_i R_i(\lambda\nu) Q^+_{\lambda\mu i} + \sum_{\lambda_1 i_1 \lambda_2 i_2} P^{\lambda_1 i_1}_{\lambda_2 i_2}(\lambda\nu) \left[Q^+_{\lambda_1\mu_1 i_1} Q^+_{\lambda_2\mu_2 i_2} \right]_{\lambda\mu} \right) |0\rangle \,, \tag{1}$$

where $|0\rangle$ is the phonon vacuum, $Q^+_{\lambda\mu i} \mid 0\rangle$ is the phonon creation operator and ν labels the excited states. The coefficients $R_i(\lambda\nu)$, $P^{\lambda_1 i_1}_{\lambda_2 i_2}(\lambda\nu)$ and the excited state energies E_ν are determined by solving the corresponding secular equation (c.f. Ref. [6]). We take into account all two-phonon terms that are constructed from the phonons with multipolarities $\lambda \leq 5$ [9].

In Fig. 1, the calculated dipole spectra of ^{132}Sn are shown. The right part of the figure shows the photo-absorption cross section up to 26 MeV. The left panel shows the low-lying part of the corresponding spectrum below 12 MeV. Figure 1 (a) displays the experimental distribution observed through Coulomb excitation experiments [10, 11]. The dots with error bars are the experimental data. Results of RPA calculations are shown in Fig. 1 (b), and the RPA plus phonon–phonon coupling (2PH) results are presented in Fig. 1 (c). The cross section is computed by using a Lorentzian smearing with an averaging parameter $\Delta = 1.0$ MeV. The general shapes of the giant dipole resonance (GDR) obtained in the 2PH are rather close to those observed in experiment. This demonstrates the improvement of a description within 2PH

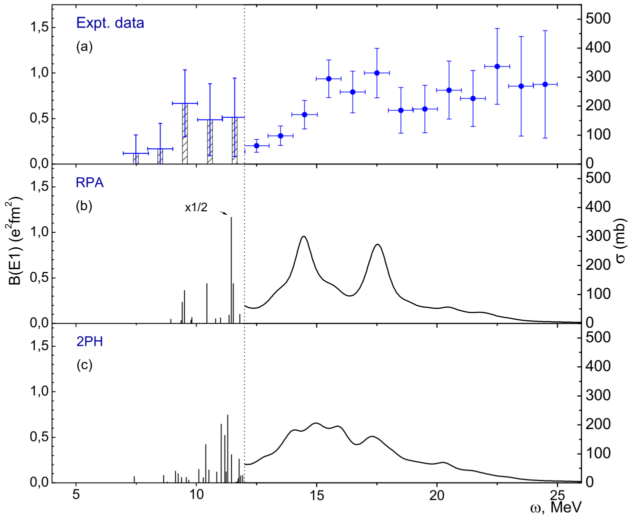

Fig. 1. B(E1) strength distribution in ^{132}Sn. Comparison of photo-absorption cross sections measured through Coulomb excitation experiments [10, 11] (a), RPA results (b), and RPA plus phonon–phonon coupling results (c).

in comparison with RPA. We conclude that the main mechanisms of the GDR formation in ^{132}Sn are taken into account correctly and consistently in the 2PH approach.

The GDR energy of 15.5 MeV is predicted by the RPA, and taking into account the phonon–phonon coupling gives rise to a decrease of the energy by 0.1 MeV, while the experimental energy corresponds to 16.1±0.7 MeV [10]. The experimental GDR width is 4.7±2.1 MeV [10] and this is in agreement with our results. The inclusion of the two-phonon terms gives a small increase of the resonance width from 4.9 to 5.0 MeV. Our results are qualitatively in agreement with other theoretical predictions [2].

We now discuss the results for the low-energy E1 strength in more detail (*c.f.* the left part of Fig. 1). For the low-lying part of the dipole spectrum, the RPA calculations predict two rather pronounced states around 9.5 and 10.4 MeV. The neutron transition densities of these levels are dominantly outside the nuclear surface. This corresponds to the vibrations of a neutron skin against a proton–neutron core. One can see from Fig. 1 (b) that the next fairly collective state is around 11.4 MeV. Analyzing the transition densities, one can conclude that this state does not belong to the PDR. The corresponding 2PH strength distributions in Fig. 1 (c) show many states with comparable strength in the energy region below 11 MeV. These states originate from the fragmentation of the RPA pygmy mode. Their transition densities have a behavior which is very similar to that of the initial RPA state.

In the RPA calculations, the centroid energy of the PDR is 9.9 MeV. Taking into account the phonon–phonon coupling gives the same value for the PDR energy, while experimentally it is 9.8±0.7 MeV [10]. Our calculations give a total dipole strength of 1.27 $e^2\mathrm{fm}^2$ for the RPA and 1.42 $e^2\mathrm{fm}^2$ for the 2PH. The summation includes the dipole states below 11 MeV [9]. The experimental value is 1.3±0.8 $e^2\mathrm{fm}^2$ [11]. The calculated total QPM [12] dipole strength in the PDR energy range of $E = 0 - 8$ MeV is about 0.36 $e^2\mathrm{fm}^2$. The PDR centroid in the QPM is equal to 7.1 MeV. On the other hand, the RQTBA [13] calculations give 7.3 MeV and the summed B(E1) value is 3.15 $e^2\mathrm{fm}^2$ for the energy interval below 10 MeV. Our calculations show that the inclusion of the two-phonon terms results in an increase of the pygmy E1-resonance width from 1.2 to 2.0 MeV. An upper limit of experimental PDR width is 2.5 MeV [10].

In summary, by starting from the Skyrme mean-field calculations, we have studied the properties of the low- and high-energy spectrum of dipole excitations of ^{132}Sn. Using the Skyrme interaction SLy4, a successful description of the pygmy and giant dipole resonance is obtained. We observe that the inclusion of the two-phonon configurations leads to an essential increase of the pygmy dipole resonance width.

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