Second random-phase approximation with the Gogny force

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The random phase approximation (RPA) is a widely used approach for the study of collective modes in many-body systems. Within this theory, the excited states are described as superpositions of of 1 particle-1 hole ($1p1h$) and 1 hole-1 particle ($1h1p$) configurations. One obvious limitation of this model is that the states which contain non negligible multiparticle-multihole components cannot be properly described. A well known extension of the RPA scheme is the second RPA (SRPA) model which is obtained with the inclusion of the 2 particle-2 hole ($2p2h$) configurations. This leads to a richer description of the excitation modes and includes also the possibility of having a better description of the width of the resonances.

For the first time, we have carried out SRPA calculations with a finite-range interaction [1]. We used a well tested parametrization of the Gogny interaction, the D1S force [2]. In our calculations, this interaction is used to generate the single particle (s.p.) basis by means of a Hartree-Fock calculations, and to carry out both RPA and SRPA calculations.

Calculations with finite-range interactions are numerically more demanding than those which use zero-range interactions. On the other hand, finite-range interactions provide a natural truncation of the s.p. configuration space. This is what happens in the calculations of the pairing effects, either in the Bardeen Cooper and Schrieffer or in the Hartree-Fock-Bogolioubov approaches. In both cases the convergence of the results with respect to the size of the configuration space is stabilized by the finite-range of the interaction. On the paper, this effect should show up also in SRPA calculations, even though from the numerical point of view this convergence is not as fast as desired. We should point out, however, that the density dependent term of our Gogny parametrization has a zero-range character which can spoil the convergence.

Another, non negligible, advantage in using the Gogny force, is that this force has been introduced, and adjusted, to be used in both the mean-field and the pairing channels. Since in SRPA, not only the standard RPA-type particle-hole matrix elements of the interaction are present, but also particle-particle matrix elements it seems more appropriate to employ a force that is well adapted also for these other kinds of terms.

To present the first applications of the full Gogny-SRPA model we have chosen the nucleus ^{16}O which allows us to check and control well the heavy numerical problem associated to the diagonalization of the SRPA matrix as well as to compare our results with those of the previous Skyrme-SRPA calculations [3]. In this report we present only results obtained for the isoscalar monopole excitation.

In the panel (a) of Fig. 1, we compare the RPA result, black line, with the full SRPA result, red dashed line. We observe that the RPA peak at 23 MeV is spread out on a wide energy range with a peak at 10 MeV. The inclusion of $2p2h$ excitations spreads the strength and generates an additional attraction in the isoscalar channel. We should point out that the calculations of the energy weighted sum rules in RPA and SRPA produce the same value. This confirms that the effect of the $2p2h$ configurations is a redistribution of the RPA strength.

The blue dashed-dotted line shows the result obtained in the so-called diagonal approximation [4], consisting in neglecting the interaction matrix elements connecting $2p2h$ excitation pairs with other $2p2h$ pairs. In this approximation the matrix elements beyond RPA are only those connecting $2p2h$ and $1p1h$ matrix elements. This approximation has been used quite often since it simplifies remarkably the numerical effort of the SRPA calculations. The result of panel (a) indicates a relatively good agreement of the results in the diagonal approximation with those of the

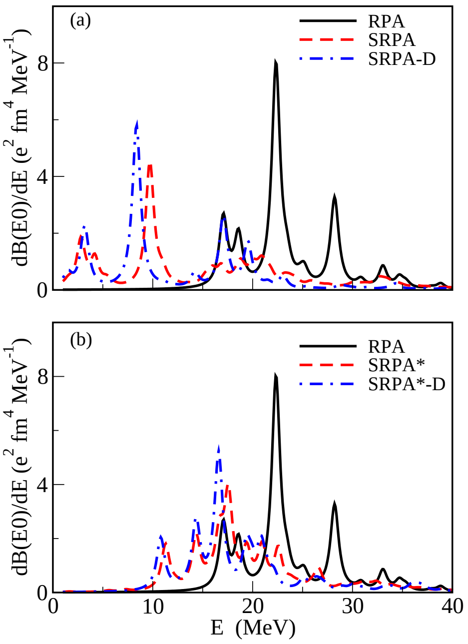

Figure 1. Strength distributions of the isoscalar monopole excitation in ^{16}O. The full lines in both panels show the RPA result. The red dashed lines show the results of the full SRPA calculations, while the blue dashed-dotted lines have been obtained by neglecting the coupling between $1p1h$ and $2p2h$ excitations, i.e. in the diagonal approximation. The SRPA results of panel (b) have been obtained by neglecting, in the $2p2h$ space, the terms connecting excitations of nucleons of different type.

complete calculation. These results are different from those obtained with the Skyrme interaction [3] where large differences with the full calculations have been found. This is another feature related to the finite range character of the interaction we used.

In order to understand better the origin of a such big shift of the SRPA strength distribution with respect to the RPA one, we carried out a more accurate analysis of the matrix elements of the residual interaction that appear only in SRPA. We found that that some neutron- proton matrix elements, appearing in the beyond- RPA block matrices, are one order of magnitude larger than the other matrix elements. To study the role of these matrix elements, we carried out calculations without the $2p2h$ matrix elements formed by nucleonic pairs of different type. For example, in these calculations we neglect matrix elements such as

$$\langle \nu^{-1}\pi | V | \nu^{-1}\pi^{-1} \rangle \quad (1)$$

where we have two neutron (ν) holes and one proton (π) $1p1h$ excited pair.

We label with a star the results obtained with this approximation, and we show them in the panel (b) of Fig. 1. The comparison with the results of the full calculation shown in panel (a), clearly indicates the relevant role played by these matrix elements. Furthermore, in these calculations the diagonal approximation is working even better than in the case of the complete calculation.

Our results indicates that in the Gogny-SRPA model the strength distributions are strongly affected by the charge-exchange type matrix elements of the residual interaction that seem to be stronger in the channel coupling the $1p1h$ configurations with the $2p2h$ ones. These matrix elements do not contribute at the mean-field level and do not enter into play in standard RPA calculations. If one wants to check and constrain their effect, it is thus important to go beyond the conventional procedures which are adopted for the fits of the force parameters.

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