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Selfconsistent mean field calculations of the nuclear response using a realistic nucleon-nucleon interaction with a density dependent corrective term

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Abstract. Tamm-Dancoff and random-phase approximations are formulated in the canonical Hartree-Fock-Bogoliubov quasi-particle basis and adopted to compute the $E1$ response in Ca isotopes using an intrinsic Hamiltonian composed of a V_{lowk} potential, deduced from the CD-Bonn nucleon-nucleon interaction, corrected with phenomenological density dependent and spin-orbit terms. Attention is focused on the evolution of the dipole strength distribution, including the low-lying transitions associated to the pygmy resonance, in going from the $N = Z$ ^{40}Ca to Ca isotopes with neutron excess.

1. Introduction

Following the procedure proposed in Ref. [1], we have solved the QRPA and quasi-particle Tamm-Dancoff approximation (QTDA) eigenvalue equations in a canonical Hartree-Fock-Bogoliubov (HFB) basis starting from a V_{lowk} potential [2], derived from the CD-Bonn NN interaction [3]. This approach may represent an alternative to the generally adopted QRPA calculations rooted in energy density functionals derived either from Skyrme forces [4] or from relativistic classical meson nucleon Lagrangians [5]. As in Ref. [1], we added a phenomenological density dependent potential which reduces drastically the too large spacing between levels produced by the V_{lowk} potential. Moreover, we added a phenomenological spin-orbit term in order to enhance the spin-orbit splitting.

We applied the formalism to neutron rich oxygen and tin isotopes [6] obtaining dipole cross sections in fair agreement with experiments. In nuclei with neutron excess, an appreciable low-energy dipole strength, comparable to the one measured in recent

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experiments [7], was obtained. The states in this region were shown to be excited by isovector and isoscalar probes, consistently with recent experimental findings [8]. We have applied here the same method to Ca isotopes and focus our attention at the low-lying states which are supposed to describe the pygmy resonance.

2. QTDA and QRPA $E1$ response in Ca isotopes

The method is illustrated in Ref. [6]. Here we just point that we have solved the QTDA and QRPA eigenvalue equations in the HFB canonical basis. In such a basis, the HFB transformation coefficients u and v from particle to quasi-particle operators assume the simple BCS form. We pay a price for that. The one-body quasi-particle Hamiltonian is no longer diagonal in the quasi-particle operators, which makes more involved the expression of the diagonal (QTDA) block of the QRPA matrix.

We consider an intrinsic Hamiltonian obtained by subtracting the CM kinetic energy T_{CM} from the shell model kinetic operator. It includes a modified one-body kinetic term and a potential $V = V_2 + V_\rho + V_{so}$ composed of three pieces. The first one $V_2 = V_{lowk} + T_2$ is the sum of the CM two-body kinetic piece $T_2 = -1/(2mA)\sum_{i\neq j} \vec{p}_i \cdot \vec{p}_j$ plus a V_{lowk} potential [2] deduced from the NN CD-Bonn force [3] with a cut-off $\Lambda = 1.9\ fm^{-1}$. The second term is a density dependent potential $V_\rho = \sum_{i<j} v_\rho(ij)$, where

$$v_\rho = \frac{C_\rho}{6}(1 + P_\sigma)\rho(\frac{\vec{r}_1 + \vec{r}_2}{2})\delta(\vec{r}_1 - \vec{r}_2). \quad (1)$$

It was introduced in Ref. [1] and was shown [9] to give to the ground state energy the same contribution of a contact three-body interaction. Our potential V includes also a spin-orbit term $V_{so} = C_{so}\sum_i \vec{l}_i \cdot \vec{s}_i$. The parameter of V_ρ was determined by the request that the peak of giant-dipole-resonance (GDR) be reproduced. The spin-orbit parameter was fitted on the empirical neutron spin-orbit separation energies. Our space, which includes up to 12 major oscillator shells, is not sufficient to decouple completely the 1^- and 0^+ spurious states from the intrinsic ones, as it should be in a fully self-consistent QRPA. On the other hand, we eliminate completely and exactly the spurious admixtures in QTDA by resorting to the Gramm-Schmidt orthogonalization procedure.

One can see from Figure 1 that V_ρ shifts the peaks down by $\sim$ 20MeV into the experimental region. The spin-orbit term induces only a redistribution of the strength. As shown in Figures 2 and 3, the QTDA to QRPA cross sections are almost identical. Both over-exhaust the TRK sum rule by a factor ~ 1.4 for all isotopes. Experimentally, the enhancement factor is ~ 1.4 in the doubly magic nuclei ^{40}Ca and ^{48}Ca and ~ 1.3 in the open shell isotopes. This enhancement is not surprising. In fact, the TRK sum rule holds only if the Hamiltonian does not contain momentum dependent terms. This is not the case for a realistic potential like the one we have adopted. The cross sections, computed with a width $\Delta = 3$ MeV, reproduce the experimental data in ^{40}Ca but underestimate the peak in ^{48}Ca. In the open shell isotopes, the data can be reproduced if a larger width ($\Delta = 6$ MeV) is used. In the isotopes with neutron excess, non negligible peaks appear in the region < 13 MeV. Their summed strengths are

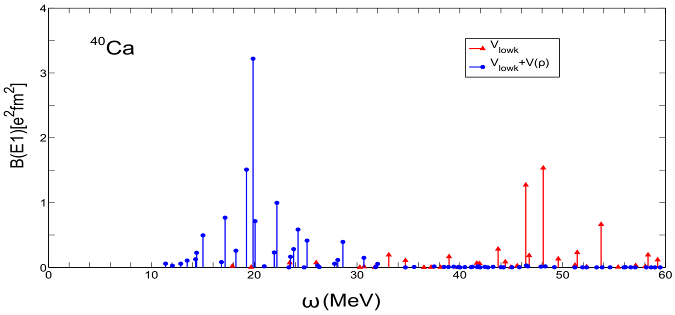

Figure 1. TDA B(E1) in ^{40}Ca with V_{lowk} and with $V_{lowk} + V_\rho$.

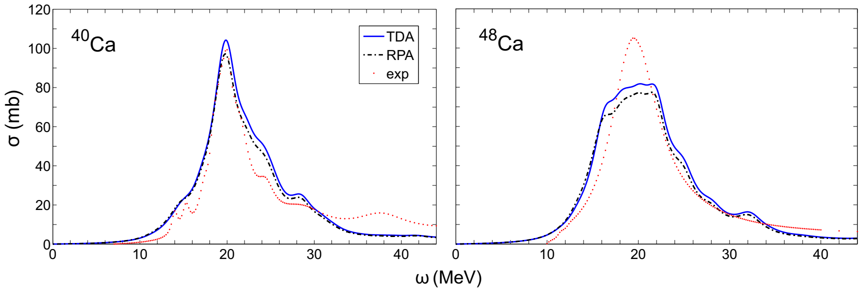

Figure 2. Comparison of the QTDA and QRPA cross sections with the experimental data for ^{40}Ca and ^{48}Ca

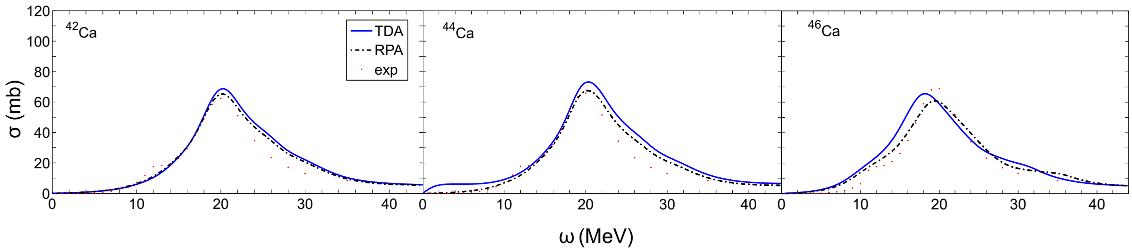

Figure 3. Comparison of the QTDA and QRPA cross sections with the experimental data for ^{42}Ca, ^{44}Ca and ^{46}Ca with $\Delta = 6$ MeV

$\sum B(E1) \sim 0.33\ e^2 fm^2$ in ^{42}Ca, $\sum B(E1) \sim 0.13\ e^2 fm^2$ in ^{44}Ca, $\sum B(E1) \sim 2\ e^2 fm^2$ in ^{46}Ca. In ^{48}Ca only one peak appears at $\omega = 11.4$ MeV and gets a strength $B(E1) = 0.13$ $e^2 fm$. As shown for ^{42}Ca in Figure 4, the 1^- states are excited by both isovector and isoscalar probes. The isoscalar strength is concentrated below and above the region of the $E1$ GDR. The high energy strength is induced by the $\sim 3\hbar\omega_0$ excitations and is associated to the compressional squeezed mode (see [10] and references therein). The low-lying isoscalar and isovector dipole spectra have a specular structure. They are both composed of two fairly high peaks and a small one. Only the lowest 1^- can be associated to the pygmy resonance due to the overwhelming dominance of its neutron component (98.5%). Moreover its dominant quasi-particle component $\mid (1d_{5/2})_n (0f_{7/2})_n \rangle$, with a weight 59%, describes valence neutrons excitations and, therefore, emphasizes the role of neutron skin.

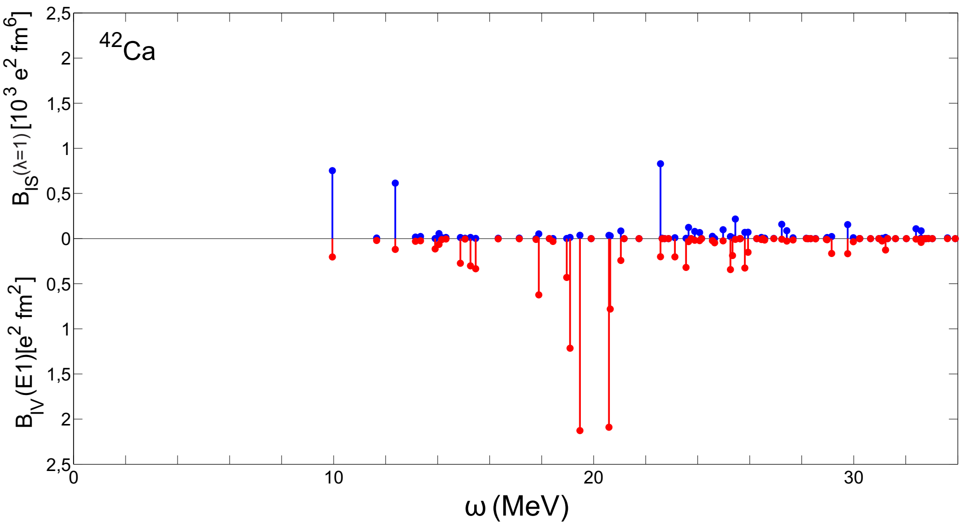

Figure 4. Comparison between isoscalar and isovector B(E1) for ^{42} Ca

In summary, the present calculation has confirmed that it is crucial to add a density dependent two-body potential V_ρ simulating a three-body contact force to V_{lowk}. The spin-orbit term improves the spectra by enhancing the spin-orbit splitting but has only a fine tuning effect on the $E1$ strength distribution. This distribution changes little in going from QTDA to QRPA for all the Ca isotopes and is compatible with the experimental data. Low-lying states collecting a non negligible low-energy dipole strength appear in nuclei with neutron excess. They are excited by both isovector and isoscalar operators and describe excitations of the valence neutrons, two signatures of the pygmy resonance.

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