Giant monopole resonances in covariant finite-amplitude method[†]

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During the past decades, the covariant density functional theory has received widespread attention because it has successfully described many nuclear phenomena[1)]. In this report, we mainly focus on the recent progress in the self-consistent relativistic random-phase approximation (RPA) established by using the finite-amplitude method (FAM).

The RPA is one of the leading theories applicable to both low-lying excited states and giant resonances. In the relativistic framework, quantitative RPA calculations were realized after recognizing the importance of the Dirac sea. Subsequently, great efforts on the relativistic RPA have been made. However, most investigations are essentially restricted within spherical symmetry. The conventional RPA calculations in the matrix form face a significant computational challenge when the number of particle-hole (ph) configurations N_{ph} becomes large.

The so-called finite-amplitude method was proposed as a promising solution for this computational challenge[2,3)]. In this method, the effects of residual interactions are numerically evaluated by considering a finite density deviation around the ground state. Thus, the self-consistent RPA calculations become possible with a slight extension of the static Hartree-Fock code. Furthermore, by using the iterative methods, the computation time linearly depends on N_{ph}, instead of N_{ph}^3, in the diagonalization scheme, which is crucial when N_{ph} becomes large.

Work is in progress for developing the self-consistent relativistic RPA by using both the iterative and matrix FAM schemes, i.e., i-FAM and m-FAM, the detailed formalism of which can be found in the original article[†].

In Fig. 1, we show the isoscalar giant monopole resonances (ISGMR) in ^{208}Pb calculated with the relativistic parametrization DD-PC1. The effects of the Dirac sea and the rearrangement terms can be examined by switching on or off the corresponding ph residual interactions.

First, the transition strengths calculated in the m-FAM scheme with and without the Dirac sea are compared in the upper panel. It is found that the Dirac sea shows profound effects on the centroid energy, and the experimental data[4)] is reproduced only when the Dirac sea is taken into account. Although the effects of the Dirac sea cannot be isolated in the coordinate-space representation, it can be clearly seen that the i-FAM results are exactly above the m-FAM results that include the Dirac sea. This confirms that these two FAM schemes are equivalent and the effects of Dirac sea can be taken into account automatically and implicitly.

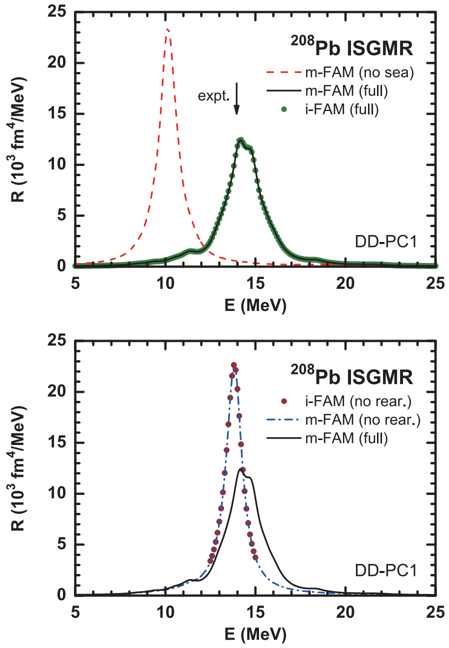

Fig. 1. ISGMR in ^{208}Pb calculated using i-FAM and m-FAM. The results calculated with and without the Dirac sea and the rearrangement terms are compared. The experimental centroid energy[4)] is denoted by the arrow.

It is tedious to calculate the rearrangement terms in the conventional RPA calculations; in contrast, in FAM, these terms can be simply taken into account by re-calculating the coupling strengths with new densities. In the lower panel, the transition strengths of ISGMR calculated using m-FAM with and without the rearrangement terms are shown, together with the i-FAM results calculated without the rearrangement terms. The equivalency of these two FAM schemes is demonstrated once more. It is also found that the rearrangement effects on the centroid energies is quantitatively substantial.

References

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