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Ab Initio Description of Collective Excitations

The theoretical description of collective excitations in nuclei with all their facets – such as giant resonances, low-lying strength, fragmentation, and fine structure – has been the domain of phenomenological models so far. Only recently, first ab initio methods have been proposed to adress the collective response. These approaches transfer the powerful ab initio tools for ground states and low-lying excitations developed over the past decade to the description of the collective response. In this way, collective phenomena can be explored in the same theoretical framework as low-lying excitations and ground-state observables, using the same state-of-the-art realistic nuclear interactions.

We present an ab initio approach to collective excitations and strength distributions build on the No-Core Shell Model (NCSM), which is one of the standard ab initio methods for the p- and lower sd-shell. We combine it with the so-called Lanczos strength-function method to directly extract the transition strength distribution of various electromagnetic modes. Using different two and three-nucleon interactions from chiral effective field theory, we investigate the electric monopole, dipole, and quadrupole response of the even oxygen isotopes from 16-O to 24-O as well as selected helium and carbon isotopes. This Strength-Function NCSM describes the full energy range from low-lying excitations to the giant resonance region and beyond in a unified and consistent framework, including a complete description of fragmentation and fine-structure. This opens unique opportunities for understanding dynamic properties of nuclei from first principles and to further constrain nuclear interactions. We demonstrate the computational efficiency and the robust model-space convergence of our approach and compare to established approximate methods, such as the Random Phase Approximation, shedding new light on their deficiencies.

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