CONFIGURATION INTERACTION SHELL MODEL APPROACH TO DIPOLE EXCITATIONS IN ATOMIC NUCLEI

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Scientific context : A powerful method to study quantum many-body systems is to apply weak external perturbations and examine their response. In nuclei, photon scattering reveals the **Giant Dipole Resonance (GDR)**, a collective oscillation of all protons against all neutrons. In neutron-rich nuclei, an additional low-energy mode, the **Pygmy Dipole Resonance (PDR)**, emerges. It corresponds to the oscillation of excess neutrons against the saturated proton-neutron core, and is directly linked to the neutron skin thickness, the symmetry energy, and ultimately the properties of neutron stars. The nuclear dipole response can be encoded in the **Photon Strength Function (PSF)**, dominated by GDR at higher energy and PDR and M1 dipole modes at lower excitation energies. PSFs are indispensable ingredients of calculations of nuclear cross sections, e.g. in **nuclear astrophysics** (s- and r-process nucleosynthesis) and in **nuclear applications** (reactors, medical isotopes). Moreover, the knowledge of the position of the GDR in light nuclei is essential to describe the interaction of **Ultra-High Energy Cosmic Rays (UHECRs)** with the cosmic microwave background, as photodisintegration governs their propagation through the Universe.

Methods : From the theoretical point of view, the PSF were first approximated by simple empirical formulae and later computed microscopically by Quasiparticle Random-Phase Approximation (QRPA). QRPA models excited states of the nucleus as harmonic oscillations around the ground state and benefits from low computational cost. While it is well suited for describing giant resonances, it struggles to accurately reproduce low-energy effects and fragmentation of PSF. In this context, **Configuration Interaction Shell Model (CI-SM)** stands as a better method to provide PSFs description: it gives the solution of the many-body problem via the Hamiltonian matrix diagonalization and it takes into account all types of correlations in the considered system. Unfortunately, the exponential growth of the basis dimensions and related numerical complexity are limiting factors for the method to be applied all over the nuclear chart. In the last years we progressed however in building the necessary CI-SM tools to perform the first detailed analysis of the GDR and PDR modes in Ne isotopes [1] and we provided systematic predictions in light nuclei for the studies of propagation of UHECR [2]. Those CI-SM studies shed light into the domain dominated so far by QRPA-type of approaches and provided a valuable insight into the microscopic origin of the collective motion.

Objectives : The purpose of this internship is to characterize electric dipole resonances in the chain of Ca nuclei within the CI-SM approach along the lines presented in Ref. [1]. Dedicated work on the derivation of the effective Hamiltonian to be used in such calculations will be necessary to achieve a satisfactory agreement with experiment and to provide publishable results. The internship shall continue as a PhD thesis, devoted to specific numerical developments enhancing the applicability of CI-SM techniques beyond the current boundary. The applications will include further investigations of collective excitations in nuclei, particularly in the context of the international PANDORA collaboration [3].

Requirements : Knowledge of quantum mechanics /nuclear many-body theory; familiarity with Linux environements and scientific programming; proficiency in English.

[1] O. Le Noan and K. Sieja, PRC 111 (6) 064308 (2025).

[2] O. Le Noan, S. Goriely, E. Khan, K. Sieja, in preparation.

[3] A. Tamii et al. , Eur. Phys. J. A59 (9) (2023) 208.