Influence of the continuum on effective nuclear forces

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Nuclear forces play decisive role in explaining nuclear shell evolutions as for instance the creation of shell gaps (and magic numbers) or at the opposite the development of collectivity. These forces are well understood in the valley of stability and start to be better known away from it. In particular, they can account for a strong and preserved magicity in the N=20 isotones from Ca (Z=20) to Si (Z=14), and its sudden and strong breaking in Mg (Z=12) and below.

When moving away from stability, eventually reaching the neutron (proton) drip lines, where the last added neutron (proton) is unbound, the nuclear forces and nuclear correlations are expected to differ significantly from those between well bound nucleons, in particular as the wave function of the unbound nucleons lies in the continuum. Despite the larger spreading of the nucleons' wave function, it is still observed that two-body NN forces have an important strength, though they could be reduced by as much as 50% for low-L orbitals. The relative change in strength between the nuclear forces when nucleons occupy different orbitals can eventually lead to a breaking of the mirror symmetry by changing the apparent spectra between nuclei in which protons and neutrons are simply interchanged. A massive breaking of this fundamental symmetry has been observed recently between ^{16}F and ^{16}N [I. Stefan et al., Phys. Rev. C 90 (2014) 014307].

Moreover, the coupling between bound states and those in the continuum (of same spin-parity) can significantly modify the energy of certain orbitals, leading to further apparent modification of two-body effective nuclear forces and a change of the properties of the levels (width, decay mode). Close to the drip line, interesting phenomena such as nuclear halos and cluster states also develop. Such states can be present, in addition to the normal states expected by a normal shell model of the nucleus.

The ^{14}B nucleus is very interesting as it combines many of the aspects related to the nuclear force and its coupling to the continuum. Indeed, this nucleus is located close to the doubly magic ^{14}C nucleus, to which a neutron is added and a proton removed to form ^{14}B. From the identified levels in ^{14}B, the proton-neutron force can be deduced for different neutron configurations. Moreover, being bound by only 970 keV, some states will likely exhibit a halo configuration, with their wave function extending far away from the nuclear core. Finally bound states will also couple to unbound states located above the neutron emission threshold and modify their intrinsic properties. This study enters in a more global understanding of nuclear forces close to the drip-lines, where certain explosive astrophysical scenarios are taking place.

During this internship period, the student(s) will analyze data from an experiment carried out in a big accelerator (GSI) in which the bound and unbound states of ^{14}B were produced from various nuclear reactions. He will get familiar with the identification of nuclei as well as neutron and gamma detection. After this done, the student(s) will interpret the results in terms of nuclear forces and coupling to the continuum, with the help of simple theoretical models. It will also be possible to predict the structure of the mirror (totally unbound) nucleus ^{14}F and see which experiment can be carried out to prove that predictions are correct or not.

Depending on the advances in detectors' developments that will be carried out by the group from September to December 2020, the student(s) will also participate in the test of gas detectors (ionization and drift chambers) that are planned to be used for future experimental campaigns at GANIL.

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