International Collaborations in Nuclear Theory: Theory for open-shell nuclei near the limits of stability

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Motivation

The pioneering activities of rare-isotope beam (RIB) facilities worldwide have ushered in a new era of nuclear physics over the past decades. With the advent of the next generation of facility upgrades, such as FRIB in the US, FAIR in Germany, and RIBF in Japan, thousands of undiscovered nuclei, often existing at the very limits of stability, will be created and studied in the laboratory. These exotic systems exhibit behavior distinct from their stable counterparts, and the quest to discover and understand their properties from first principles represents a cornerstone of modern nuclear science.

Since much of nuclear structure theory has been developed in the context of stable systems, one of the central theoretical challenges in the next few years will be to develop new or extend existing models to elucidate and predict the novel features of nuclei at the limits of stability.

At the heart of this theoretical effort are three fundamental issues that must be confronted:

- the effects of many-nucleon, in particular three-nucleon (3N)

Plans for the workshop

The workshop aims at addressing three important theoretical topics in the analysis of present and future experiments. These are

- Construction of effective Hamiltonians for nuclei close to the driplines
- Advances in large-scale computations of many-body systems
- Applications to nuclear physics observables

The first topic of the program will focus on constructing non-empirical valence-space Hamiltonians and effective operators using *ab initio* many-body methods starting from the underlying two- and three-body interactions between nucleons. We will explore how this can be achieved within different *ab initio* frameworks, and the potential to use the resulting non-empirical valence-space Hamiltonians as a possible benchmark between many-body theories. We will also examine how such non-empirical valence Hamiltonians can serve as an improved starting point for the development of empirical shell model interactions adjusted to data.

The workshop will also focus on advancements in large-space

Scientific goals

1) Construction of effective Hamiltonians for nuclei close to the driplines

The framework of many-body perturbation theory (MBPT) has been used in the past for constructing effective valence-space Hamiltonians, but it is known to suffer a number of shortcomings (issues of convergence, sensitivity to harmonic oscillator frequency, etc.), and extending it to nuclei near the drip lines requires numerous non-trivial extensions. While MBPT has previously been used calculate valence-shell interactions for medium-mass nuclei based on NN+3N forces, recently a number of improved non-perturbative methods have been developed for this purpose. A prescription exists to construct a valence-space Hamiltonian from no-core shell model calculations but is currently limited to p-shell nuclei. The first nonperturbative technique for constructing valence-space Hamiltonians in medium-mass nuclei that is computationally feasible is the in-medium similarity renormalization group (IM-SRG), which decouples orbitals outside a given valence space through a continuous sequence of unitary transformations.

Possible additional topics

Developing theoretical uncertainties

Global theoretical studies of isotopic chains, such as the chains of calcium, nickel or tin isotopes, make it possible to test systematic properties of nuclear models, although a quantitative comparison of various experimental data with quantified theoretical uncertainties still remains a major challenge for nuclear science. To address this shortcoming, we would also like to focus on developing reliable theoretical error bars in many-body calculations of open-shell nuclei. This is a multifaceted endeavor that will involve examining the interplay of uncertainties from various sources such as effective field theory (EFT) truncation errors and uncertainties in the fitted parameters of the input EFT interactions, truncated renormalization, basis-set truncation errors, and truncation errors in the particular level of many-body approximation.

Contact

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