Nuclear *ab initio* spectroscopy

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CEA, Orme des Merisiers Campus, 91191 Gif-sur-Yvette, France

I. SCIENTIFIC ISSUE

Microscopic approaches to the nuclear many-body problem aim at describing the nucleus as a collection of interacting nucleons. The specificity of *ab initio* methods lies in the fact that inter-nucleon interactions are derived systematically and consistently with the underlying physics, i.e., quantum chromodynamics (QCD) the gauge theory of the strong force. Ground and excited state observables are then obtained through the use of many-body methods that must deliver controlled approximations of the eigenstates of the nuclear Hamiltonian.

The difficulty in the systematic description of nuclear excited states comes from the diversity of their nature. Sometimes well described as individual nucleonic excitations, sometimes resulting from a collective motion (resonance) of all nucleons of the system at once, their systematic description requires to tackle these different phenomena spanning distinct scales with the same accuracy. Another challenge and open-problem for *ab initio* methods relates to the computation of electromagnetic transition strengths in nuclei (such as B(E2)). While low-lying 2^+ states are usually accurately described at low-orders in different many-body expansions (e.g. coupled-cluster with singles, doubles and triples excitations), the B(E2) can in some cases be as much as an order of magnitude smaller compared to data and other phenomenological models that employ effective charges.

Ab initio methods were originally limited to light systems (using "exact" methods) before being extended to ground states of doubly closed-shell nuclei thanks to the introduction of single-reference (SR) expansion methods. In recent years, these methods have been extended to open-shell and deformed nuclei. This has typically been achieved following several complementary paths:

- Valence-space calculations, where valence nucleons are first decoupled from a frozen (closed-shell) core and from excitations outside that valence space through a single-reference calculation. The nuclear many-body problem becomes exactly solvable in the reduced model space of the valence nucleons.

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- Many-body expansion methods (e.g. CC and IMSRG) built on top of a symmetry-breaking reference state. Here low-lying collective excitations can be accessed via symmetry-projection techniques.
- Equation of motion (EOM) methods build particle-hole excitations on top of a correlated ground state wave-function to access (non-collective) excited states.
- Multi-reference (MR) expansion methods generalize single-reference approaches by realizing the expansion in terms of elementary excitations on top of a reference state that itself combines a reduced manifold of simple product states.

The last two categories of methods can possibly be combined with a pre-processing of the Hamiltonian via an in-medium similarity renormalization group (IMSRG) transformation to accelerate the resummation of correlations.

These approaches, as well as their variants and combinations, all carry their own strengths and shortcomings and offer complementary descriptions of nuclear spectroscopy. This workshop will cover state-of-the-art methods to address nuclear spectroscopy within an *ab initio* perspective from light to medium-mass nuclei and discuss the envisioned developments for the years to come.

II. GOALS

The main goals of the workshop are

1. to review existing *ab initio* approached to nuclear spectroscopy in light- and medium-mass nuclei,
2. to discuss limitations of current methods and possible workarounds.

III. PROGRAM

Structure

The meeting takes place over 4 days.

Scientific talks

- R. Roth (TU Darmstadt) *Mid-mass low-lying spectroscopy via in-medium no-core shell model calculations*
- J. Holt (TRIUMF) *Mid-mass low-lying spectroscopy via valence-space in-medium similarity renormalization group calculations*
- Z. H. Sun (ORNL) *Mid-mass low-lying spectroscopy via valence-space coupled cluster calculations*
- J. M. Yao (Sun Yat-sen University) *Low-lying spectroscopy of even-even nuclei via projected generator coordinate method calculations with a multi-reference in-medium similarity renormalization group pre-processing of the Hamiltonian*
- B. Bally (CEA DRF) *Mean-field approximation on steroids: description of the deuteron*
- M. Frosini (CEA DES) *Low-lying spectroscopy of even-even nuclei via multi-reference perturbation theory based on a projected generator coordinate method reference state*
- A. Tichai (TU Darmstadt) *Mid-mass low-lying spectroscopy via valence-space density matrix renormalization group calculations*
- S. Bacca (Mainz University) *Collective excitations of even-even closed-shell nuclei via lorentz integral transform coupled cluster calculations*

- C. Barbieri (Milan University) *Collective excitations of even-even closed-shell nuclei via Dyson self-consistent Green's function calculations*
- A. Porro (TU Darmstadt) *Collective excitations of even-even open-shell nuclei via projected generator coordinate method and quasi-particle random-phase approximation calculations*
- G. Stellin (CEA DRF) *Spectroscopy of even-even singly open-shell nuclei via Gorkov self-consistent Green's function calculations*
- V. Somà/A. Scalesi (CEA DRF) *Low-lying spectroscopy of odd-even open-shell nuclei via Gorkov self-consistent Green's function calculations*
- H. Hergert (MSU) *Low-lying spectroscopy of near closed-shell nuclei via equation-of-motion in-medium similarity renormalization group calculations*
- T. Papenbrock (ORNL) *Low-lying spectroscopy of nuclei via coupled cluster techniques*
- L. Gonzales-Miret (CEA DAM) *Systematic of isovector electric and magnetic dipole strength functions via the FAM-QRPA*
- A. Roux (CEA DAM) *Emulation of PGCM calculations using the eigenvector continuation method*

Schedule

(Bdg,room)	Tuesday (703,135)	Wednesday (703,135)	Thursday (713C,Galilée)	Friday (703,135)
9h15	Welcome			
9h30	**Roth**	**Papenbrock**	**Frosini**	**Holt**
10h30	Break	Break	Break	Break
11h00	**Bally**	**Yao***	**Barbieri**	**Roux**
12h00	Lunch	Lunch	Lunch	Lunch
13h30	**Bacca**	**Somà/Scalesi**	**Hergert**	**Stellin**
14h30	**Porro**	**Sun***	**Tichai**	**Gonzales-Miret**
15h30	Break	Break	Break	Break
16h00	**Discussion**	**Discussion**	**Discussion**	**Discussion**
17h00	End	End	End	End