PhD-thesis of Gustav R. Jansen: « Coupled-cluster theory for open-shell nuclei »

A reliable solution of a nuclear many-body problem with the QCD motivated interactions and in the space of both discrete and continuum states would open new horizons for high precision low-energy nuclear spectroscopy. We are still far away from this Holy Grail of modern nuclear structure theory. Firstly, a nucleus is never an isolated closed quantum system but communicates with other nuclei through virtual excitations, decays and captures. Secondly, a comprehensive link between QCD and nuclear interaction which is developed by methods of the Effective Field Theory (EFT) leads to genuine many-body interactions. Finally, even if the bare interaction acts only between two nucleons, the effective interaction contains not only 2-body terms but also 3-body and higher order terms. None of the most advanced theoretical approaches nowadays is able to treat these various aspects of nuclear many-body problem satisfactorily. The resulting wave functions are very complicated and it is not even obvious whether the simple shell model will emerge as a good approximation.

The thesis of Gustav Jansen is at the center of actual discussion. It provides a step forward in the quest for a comprehensive microscopic many-body theory of nuclear structure which describes all nuclei that can exist using the same many-body Hamiltonian. His attempts made within the framework of Coupled-Cluster (CC) approach, led to the development of new methods for nuclei that can be described as two particles attached to or removed from closed (sub-)shell nuclei. These methods which are formulated in the 2p-2h truncated CC expansion, open the applicability of the CC approach for open-shell nuclei. The idea in this approach is based on the shell model picture of a nucleus consisting of an inert core and valence nucleons. Is this attempt of reconciliation between the shell model and the many-body theory successful? I am not convinced that we have got an answer to this fundamental question. Indeed, one would have to go beyond the 2p-2h truncated CC expansion and include at least 3-body terms to address this problem. Nevertheless, one of this method, the (two-)particle attached equation-of-motion coupled-cluster method, has been compared in this dissertation with the exact solution in a small basis. Few systems/states in light nuclei have been identified as apt for the description in the equation-of-motion CC approach. It was argued in the thesis that this approach should perform better in heavier nuclei.

The second important goal of this dissertation is an attempt to describe medium mass nuclei using the (two-)particle attached equation-of-motion CC approach. These studies have been accompanied by an analysis of the convergence and the center-of-mass contamination. The latter problem is crucial for all practical CC applications. Earlier studies have demonstrated an approximate factorization of an intrinsic and a center-of-mass parts in CC calculations for ground states of ^{4}He and ^{16}O. This problem appears in the dissertation as more subtle than thought previously.

The successful description of binding energy and spectra in CC approach requires inclusion of the three-nucleon interaction. This difficult problem has been approached in the dissertation of Gustav Jansen using the density-dependent two-body force obtained by integrating one nucleon line on all three-body diagrams obtained in N^2LO approximation of the chiral EFT. This way of approximating the three-nucleon forces, inspired by Zuker's ideas in shell model, allows for a successful description of energy spectra in oxygen, calcium, and titanium isotopes. CC predictions concerning excited states in these isotopes are strongly affected by the proper treatment of the continuum coupling.

Several problems raised in this PhD thesis are very inspiring and, certainly, will be further studied by the CCM collaboration. They have been formulated and advanced in this PhD thesis of high scientific standard. The thesis is written as an extended introduction and résumé of four papers. In all papers, the contribution of Gustav Jansen is very significant. In two papers, Gustav Jansen is the first author. In one paper, he is even a single author. These records prove his great independence in research and confirm his significant contribution to the modern microscopic nuclear structure theory. The introductory part is written with a certain panache. The presentation of main results of the thesis and conclusions are well organized and the presentation is clear and lucid.

To summarize, Gustav R. Jansen presents a very interesting thesis which includes new exciting results in the *ab initio* theory of many-body systems. Many of these results will influence thinking about the strategy to determine nuclear interactions and find a reliable solution of a nuclear many-body problem. One expects that a reliable nuclear many-body theory could and should explain why the shell model is so successful, which interactions lead to it and where it becomes useless. Beyond doubt I recommend that the thesis of Gustav R. Jansen should be admitted for public defense.

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Professor Marek Ploszajczak	Associate Professor Scott Bogner	Professor Trine Tveter
Marek Płoszajczak	Scott Bogner	