Nuclear Theory Seminar

Towards ab-initio Nuclear Shell Model

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Nuclear configuration-interaction approach is a powerful approach in nuclear structure. The method is based on the diagonalization of a realistic Hamiltonian containing nucleonic kinetic energies and internucleon interactions in the model space spanned by many-body spherical harmonic-oscillator configurations. However, solution of the eigenproblem for all A nucleons in a sufficiently large model space is possible only for nuclei with A<16. Such an approach is known as no-core shell model (NCSM).
For heavier nuclei, truncations have to be imposed. For the description of low-energy structure, a typical approximation is to solve the eigenproblem only for valence nucleons, placed in a model space comprised of one or two oscillator shells beyond a closed-shell core (valence-space shell model). Then an effective Hamiltonian and effective transition operators have to be introduced. Up to now, most ofthe success in the description of available experimental data is achieved by phenomenological effective Hamiltonians, adjusted to some selected set of data for valence space nuclei. Microscopic derivation of effective Hamiltonians and transition operators from realistic nucleon-nucleon interactions have been a long-standing challenge of nuclear structure. From 50's many-body perturbation theory was basically the only tool, however, convergence issues hampered applications.

In recent years, novel non-perturbative techniques for construction of valence-space shell-model Hamiltonians have been developed. We present the one of them, which is based on the Okubo-Lee-Suzuki unitary transformation of the NCSM solution [1-3]. We start with the NCSM calculations for A=16-18 in a very large basis to derive a charge-dependent effective Hamiltonian for the sd shell, which allows to exactly reproduce selected NCSM spectra of A=18 isobars. Comparison of NCSM and valence-space obtained spectra of other sd shell nuclei confirms that induced effective many-body forces play a minor role. In addition, we construct effective single-particle matrix elements of electric quadrupole (E2) and magnetic dipole (M1) operators by matching them to the NCSM results on electromagnetic transitions and moments for A=17 O and F [4]. This procedure allows us to obtain orbital-dependent effective E2 and M1 operators.

Finally, we perform systematic comparison of valence-space results on excitation spectra with experiment and with the results obtained from the phenomenological USDB Hamiltonian. Among various nucleon-nucleon potentials, Daejeon16 proposes the best agreement with experiment.

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[2] N.A. Smirnova, B.R. Barrett, Y. Kim, I.J. Shin, A.M. Shirokov, E. Dikmen, P. Maris, J.P. Vary, Phys. Rev. C100, 054329 (2019).
[3] I.J. Shin, N.A. Smirnova, A.M. Shirokov, Z. Yang, B.R. Barrett, Zh. Li, Y. Kim, P. Maris, J.P. Vary, Phys. Rev. C110, 034306 (2024).
[4] Zh. Li, N.A. Smirnova, A.M.Shirokov, I.J. Shin, B.R. Barrett, P. Maris, J.P. Vary, World Scientific. September 2025, pp. 135-154.