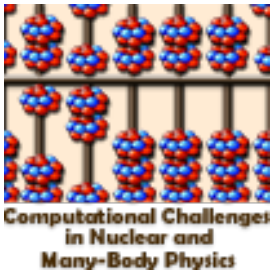

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Open-shell systems via symmetry (broken and) restored coupled cluster theory

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Ab initio many-body methods have been developed over the past ten years to address closed-shell nuclei up to mass $A \sim 130$ on the basis of realistic two- and three-nucleon interactions. A current frontier relates to the extension of those many-body methods to the description of open-shell nuclei. Several routes are currently under investigation to do so among which one relies on the powerful concept of spontaneous symmetry breaking. Singly open-shell nuclei can be efficiently described via the breaking of U(1) gauge symmetry associated with particle-number conservation, as a way to account for their superfluid character. Doubly open-shell nuclei can be addressed by further breaking SU(2) symmetry associated with angular momentum conservation. Still, the description of finite quantum systems eventually requires the exact restoration of symmetry quantum numbers. In this context, we discuss two recent developments performed within the frame of single-reference coupled cluster theory. First, we present the Bogoliubov coupled cluster formalism, which consists of representing the exact ground-state wave function of the system as the exponential of a quasi-particle excitation cluster operator acting on a Bogoliubov reference state. Test calculations for the pairing Hamiltonian are presented along with realistic proof-of-principle calculations of even-even nuclei with $A \approx 20$. Second, we discuss a recent extension of symmetry-unrestricted coupled-cluster theory that allows for the exact restoration of the broken symmetry at any truncation order. The formalism, which encompasses both single-reference coupled cluster theory and projected Hartree-Fock theory as particular cases, permits the computation of usual sets of connected diagrams while consistently incorporating static correlations through the highly non-perturbative restoration of the symmetry. A key difficulty relates to the necessity to handle generalized energy {\it and} norm kernels for which naturally terminating coupled-cluster expansions are indeed obtained. The focus is on SU(2) and U(1) symmetries but the formalism can be extended to any (locally) compact Lie group and to discrete groups, such as most point groups.

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