Nuclear ab intio methods

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Outline

Introduction

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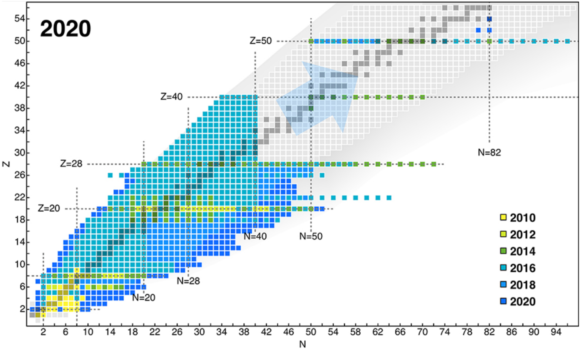

Figure: H. Hergert, Front. Phys. (2020)

Ab initio methods: Methods for solving the quantum mechanical many-body problem for all constituent nucleons, which

- describe the atomic nucleus from the bottom up with the bare nuclear forces compatible with the symmetries of QCD.
- This is done either exactly for very light nuclei or by employing certain well-controlled approximations for heavier nuclei.

Introduction

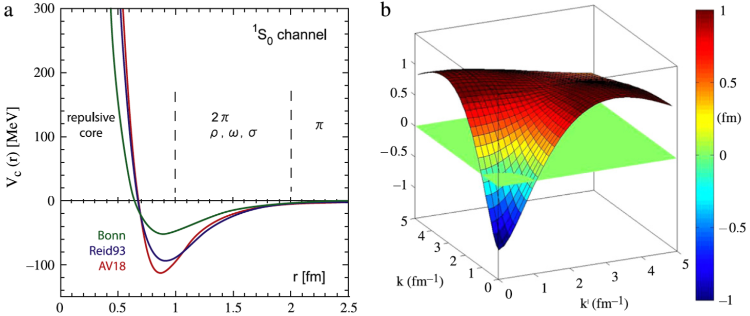

Figure: Several phenomenological NN potentials in the $^1S_0$ channel and momentumspace matrix elements of the Argonne v18 (AV18) $^1S_0$ potential after Fourier (Bessel) transformation. S.K. Bogner et al. Prog. Part. Nucl. Phys. 65 (2010) 94.

- Nuclear structure calculations are complicated due to the coupling of low to high momenta by these potentials.

The Brueckner-Hartree-Fock (BHF) theory

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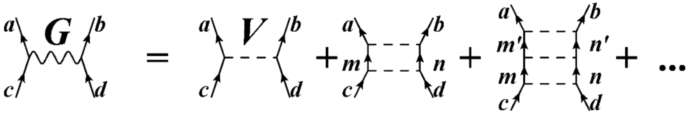
The G matrix is given by:

$$\langle ab|G(W)|cd\rangle = \langle ab|V|cd\rangle + \sum_{mn}\langle ab|V|mn\rangle \frac{Q(m,n)}{W-\varepsilon_m-\varepsilon_n}\langle mn|G(W)|cd\rangle$$



- W is the starting energy, its value depends on the position of G-matrix in the diagram.
- ϵ_m, ϵ_n are the HF single-particle energies.
- Q is the Pauli operator which forbids the states being scattered below Fermi surface.

K. Brueckner, C. Levinson, H. Mahmoud, Phys. Rev. 95, 217 (1954)

The Brueckner-Hartree-Fock (BHF) theory

- The HF equation is given by:

$$\sum_j (T+U)_{ij} D_{ja} = \varepsilon_a D_{ia},$$

where the one-body mean-field potential is

$$U_{ij} = \sum_{c=1}^{A} \langle ic|\bar{G}(W)|jc\rangle.$$

Rel. BHF: S.H. Shen et al., Prog. Part. Nucl. Phys. 109, 103713 (2019).

The Brueckner-Hartree-Fock (BHF) theory

Procedure of the (R)BHF calculation

1. Initial single-particle basis $\{|i\rangle\}$ trial for RBHF final solution $\{|a\rangle\}$
2. Bethe-Goldstone equation $$\bar{G}_{aba'b'}(W) = \bar{V}_{aba'b'} + \frac{1}{2}\sum_{cd} \frac{\bar{V}_{abcd} Q(c,d)}{W - \varepsilon_c - \varepsilon_d} \bar{G}_{cda'b'}(W),$$
   Solving with matrix inversion method
   M. Haftel and F. Tabakin, *NPA* **158**, 1 (1970)
3. Single-particle potential $$U_{ab} = \sum_{c=1}^{A} \langle ac|\bar{G}(W)|bc\rangle.$$
4. RHF iteration $$\sum_j (T_{ij} + U_{ij}) D_{ji'} = \varepsilon_{i'} D_{ii'},$$

   If converged $\{|i'\rangle\} = \{|i\rangle\} = \{|a\rangle\}$, RBHF iteration finishes.
5. Basis transformation $$\bar{V}_{k'l'm'n'} = \sum_{klmn} D^*_{kk'} D^*_{ll'} D_{mm'} D_{nn'} \bar{V}_{klmn}.$$
   Go back to step 2.

The no-core shell model

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- The

The Monte-Carlo methods

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The many-body perturbation theory

Spontaneous symmetry breaking

- The

The coupled-cluster theory

Spontaneous symmetry breaking

- The

The in-medium similarity renormalization group

Spontaneous symmetry breaking

- The