A nuclear point-coupling model and its applications

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Relativistic mean field (RMF) models are quite successful in describing ground-state properties of finite nuclei and nuclear matter properties. They describe the nucleus as a system of Dirac nucleons that interact in a relativistic covariant manner via mean meson fields [1]. The meson fields produce a finite range (FR) effective interaction. An alternative is the point coupling model (RMF-PC) where nucleons are interacting directly via contact terms together with derivative terms that simulate to some extend finite-range effects [2].

One can view RMF-PC as an approach that lies in between the RMF-FR approach and the nonrelativistic Skyrme-Hartree-Fock (SHF) approach which is also a well-developed self-consistent mean-field model that performs very well (for a review see [3]). Whereas SHF is based upon density-dependent contact interactions with extensions to gradient terms, kinetic terms, and the spin-orbit interaction, RMF-FR is based upon a coupled field theory of Dirac nucleons and effective meson fields treated at the mean-field level, where density dependence is modeled by nonlinear meson self couplings and the role of gradient terms is taken over by the finite ranges of the mesons. A comparison of RMF-PC and SHF addresses the differences between in-medium Dirac and Schrödinger nucleons, whereas a comparison of RMF-PC and RMF-FR addresses the absence *vs.* presence of finite range and the different treatments of density dependence.

The elementary building blocks of the point-coupling vertices are two-fermion terms of the type

$$(\bar{\psi}\mathcal{O}_\tau\Gamma\psi) \quad , \quad \mathcal{O}_\tau \in \{1,\tau_i\} \quad , \quad \Gamma \in \{1,\gamma_0\} \qquad (1)$$

with ψ the nucleon field, τ_i the isospin matrices and Γ one of the 4x4 Dirac matrices. We use 4 fermion terms with corresponding derivative terms and higher order terms in both the scalar and vector density. The model studied here contains 9 parameters. To estimate its predictive power compared to established mean-field approaches, we performed a fit in the manner it was done to fit the RMF-FR force NL-Z2 [4]. The resulting force is called PC-F1.

In figure 1 we compare the results for the observables that were part of the fitting procedure. We see that while NL-Z2 performs a bit better for binding energies and surface thicknesses, PC-F1 is superior with respect to radii.

Comparing the predictions for isotopic and isotonic chains, density-related observables, fission barriers, spin-orbit splittings and nuclear matter [5], we find overall agreement with the predictions from the RMF-FR model. The spin-orbit splittings can be reproduced with similar quality as with the meson model, showing that the relativistic framework is superior to the SHF model in that respect. It agrees with the RMF-FR model predicting a doubly-magic superheavy nucleus $^{292}120_{172}$.

The RMF-PC will serve as a tool to understand more deeply the structures of RMF and SHF in comparison, particularly the impact of nucleon kinematics and of the density dependence.

References

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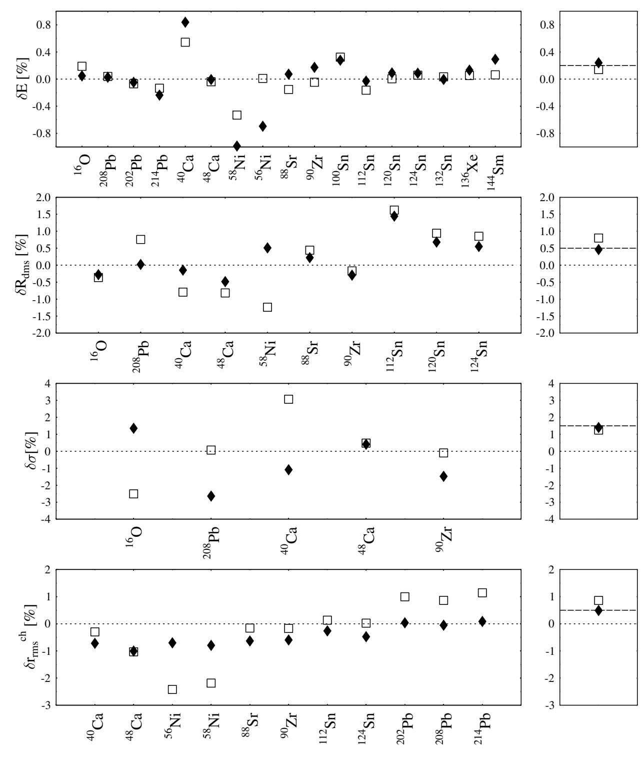

Figure 1: Errors in percent for the observables binding energy, diffraction radius, surface thickness and rms charge radius for PC–F1 (filled diamonds) and NL–Z2 (open squares) are seen on the left. The right panels show the absolute mean errors for the corresponding observables, where the dashed lines indicate the chosen relative errors ΔO in the fitting procedure.