Constraining the Nuclear Energy Density Functional by Low-Energy QCD ◊

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A relativistic nuclear energy density functional

$$E_0[\rho] = E_{\rm free}[\rho] + E_{\rm H}[\rho] + E_{\rm coul}[\rho] + E_\pi[\rho] \qquad (1)$$

has been developed, guided by two important features that establish connections with chiral dynamics and the symmetry breaking pattern of low-energy QCD:

1. large scalar and vector mean fields (with opposite sign) related to in-medium changes of QCD vacuum condensates [1], determining the Hartree energy functional $E_{\rm H}[\rho]$;

2. long- and intermediate-range interactions generated by one-and two-pion exchange and derived from in-medium chiral perturbation theory [2], with explicit inclusion of $\Delta(1232)$ excitations, determining the exchange correlation energy functional $E_\pi[\rho]$.

We have constructed a point-coupling model with density dependent interaction terms, in which the single terms of (1) reads [3]

$$\begin{aligned}
E_{\rm free}[\rho] &= \int d^3r \, \langle\phi_0|\bar\psi[-i\boldsymbol{\gamma}\cdot\boldsymbol{\nabla} + M_N]\psi|\phi_0\rangle \, , && (2)\\
E_{\rm H}[\rho] &= \frac{1}{2}\int d^3r \, [G_S^{(0)}\rho_S^2 + G_V^{(0)}\rho^2] \, , && (3)\\
E_\pi[\rho] &= \frac{1}{2}\Big\{\int d^3r \, [G_S^{(\pi)}(\rho)\rho_S^2 + G_V^{(\pi)}(\rho)\rho^2] \\
&\quad + \int d^3r \, [G_{TS}^{(\pi)}(\rho)\rho_{S3}^2 + G_{TV}^{(\pi)}(\rho)\rho_3^2] \\
&\quad - \int d^3r \, [D_S^{(\pi)}(\vec\nabla\rho_S)^2\Big\} \, , && (4)\\
E_{\rm coul}[\rho] &= \int d^3r \, A^0 e\frac{1+\tau_3}{2}\rho \, . && (5)
\end{aligned}$$

The overall structure of $E_0[\rho]$ is reminiscent of what is commonly introduced for relativistic atomic systems in a DFT approach [4]. E_π plays the role of the exchange correlation term $E_{\rm exc}$ and $E_{\rm H}$ is the nuclear counterpart of the Hartree term.

This approach has been tested in the analysis of ground-state observables of spherical and deformed nuclei. In Fig. 1 we show recent results of an extensive study of ground-state properties of deformed isotope chains with $60 \leq Z \leq 80$, calculated in the Relativistic Hartree-Bogoliubov approximation [5].

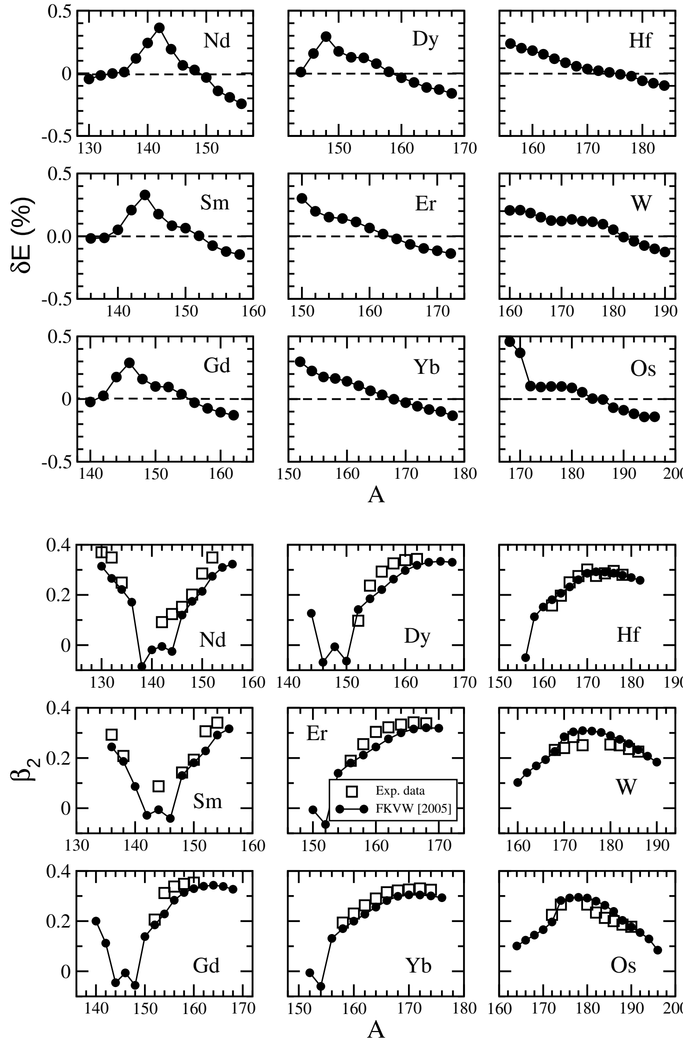

Fig. 1: The deviations (in percent) of the calculated binding energies and the predictions for the ground-state quadrupole deformations of the Nd, Sm, Gd, Dy, Er, Yb, Hf, W, and Os isotopes.

The agreement with experimental data is very good over a wide range of isotopic chains and it demonstrates the validity of our basic assumptions. Study of collective excitations is in progress.

References

[1] T. D. Cohen, R. J. Furnstahl, D. K. Griegel and X.m. Jin, Prog. Part. Nucl. Phys. **35** (1995) 221
[2] S. Fritsch, N. Kaiser and W. Weise, Nucl.Phys. **A750** (2005) 259
[3] P. Finelli, N. Kaiser, D. Vretenar and W. Weise, Nucl.Phys. **A 735** (2004) 449
[4] R.M. Dreizler and E.K.U. Gross, Density Functional theory, Spinger-Verlag, 1990; R.M. Dreizler, Lect. Notes Phys. **620** (2003) 123
[5] P. Finelli, N. Kaiser, D. Vretenar and W. Weise, [arXiv:nucl-th/0509040], Nucl. Phys. A . (in print)

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