Energy systematics of heavy nuclei in mean field models

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Introduction

Self-consistent mean field models are the most feasible means for the microscopic description of ground state properties and low-energy collective dynamics of nuclei. These models are also employed for the study of compact stars, since they can be easily extended to include the contributions from hyperons and exotic phenomena. The three most prominent self-consistent mean field models are the Skyrme Hartree-Fock approach (SHF), the Gogny force , and the relativistic mean field model (RMF). We shall focus on SHF and RMF in comparison. SHF, as the name suggest, is based on the Skyrme energy functional derived from a zero-range effective interaction. The RMF models are based on an effective Lagrangian density which describes the interactions of nucleons through the exchange of the scalar-isoscalar (σ), vector-isoscalar (ω) and vector-isovector (ρ) meson fields.

One key problem is that all SHF functionals show a systematic trend to underbinding for super-heavy elements while traditional RMF parameterizations show an opposite trend. It is the aim of the present contribution to study this discrepancy in more detail. We shall compare the binding energy systematics for all the known 513 even-even nuclei computed using the standard and extended versions of the RMF models and the SHF models.

Choices for the models

We have considered four different forces for both the RMF and SHF models. The specific reasons for choosing these forces are as follows. We employ the RMF parameterizations: NL3, TM1, FSUGold, and BSR4. The non-linear part of the Lagrangian density for these RMF models are not the same. The Lagrangian density associated with the parameter set NL3 which represents the standard RMF model contains non-linear term only for the σ meson self-interaction. The Lagrangian density corresponding to the parameter set TM1 is extended to include the self-interaction term also for the ω mesons. The FSUGold parameter set further includes the $\omega-\rho$ cross-interaction term. The Lagrangian density corresponding to the BSR4 parameter set includes all the cross-interaction terms for σ, ω and ρ mesons up to quartic order, but, the self-interaction of the ω-meson is switched off. These parameter sets should enable us to delineate the effects of the meson self- and cross-interactions on the binding energy systematics. We neglect the contributions from the self interaction of ρ mesons as they can affect the properties of the finite nuclei and neutron stars only marginally.

At the side of SHF, we consider the following four parameterizations: SkI3 , SLy6, BSk4 and SV-min The form of the SHF functional is basically the same for all four cases with the tiny difference that SkI3 and SV-min include an isovector contribution to the spin-orbit term . The parameterizations differ mainly in the bias and choice of data for the phenomenological adjustment.

Results and Summery

In Fig. 1 we summarize the errors in binding energies for all experimentally known even-even nuclei. The upper block collects the results from RMF and the lower block those from SHF. In each block the most recent parameterizations perform visibly best. This concerns BSR4 in the RMF block and BSk4

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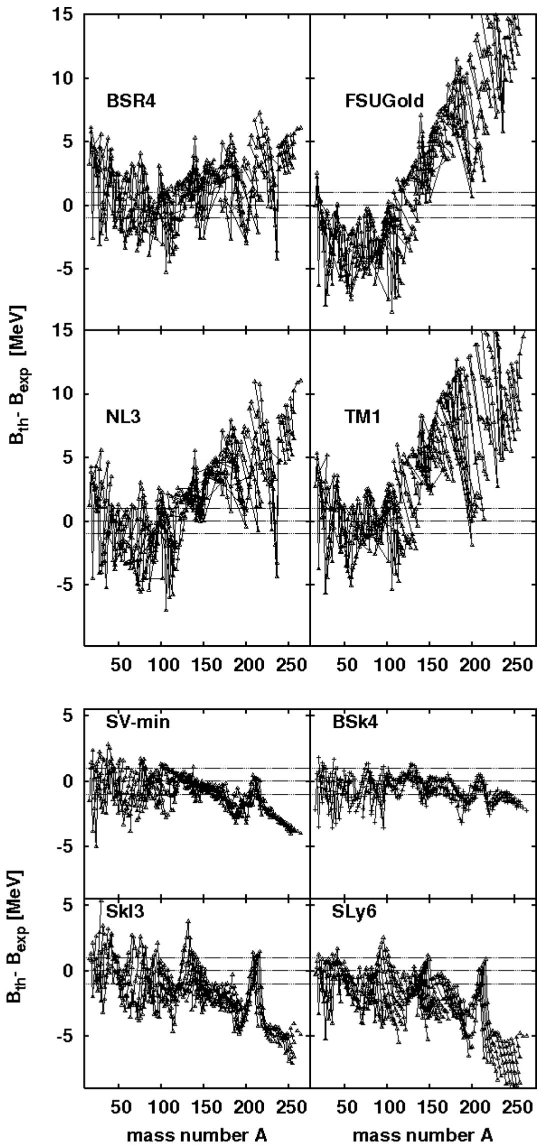

FIG. 1: Errors in the binding energy versus the mass number obtained for different parameterizations of the RMF (upper block) and SHF (lower block). The nuclei that were included in the fit are marked by filled squares, well-deformed nuclei by open circles, and all others by triangles. Binding energy error equal to zero and ± 1 MeV are indicated by faint horizontal lines. The corrections to the binding energies due to the pairing and quadrupole correlations are included for all the cases.

as well as SV-min in the SHF block. We have indicated the present "state of the art" by ± 1 MeV error bars and these three most recent parameterizations stay close to this goal. It is also found as a general rule that robust spherical nuclei in most parameterizations, are usually somewhat better described than soft or deformed nuclei.

The binding energies for the super-heavy nuclei ($A > 220$) for the RMF and SHF models are significantly different from the experimental data. *The SHF drives to underbinding of super-heavy nuclei while RMF shows just the opposite trend.* This trend on a much larger data basis confirms what had been observed in [1]. The absolute errors in the binding energies for the BSR4 parameterization [2] of the extended RMF model which includes contributions from all the cross-interaction terms are comparable to that for the SHF models. Other RMF models considered yield much larger values for the absolute errors in the binding energies for super-heavy nuclei.

Comparing the three best performers, BSR4, BSk4 and SV-min, we see that both models are approaching good control over the energies for super-heavy elements. And yet, there remains an unresolved trend which still is distinctively different between SHF and RMF. The defect seems to come from the deformation energy because the large deviation develops with deformation. This, in turn, localizes the differences in the modeling of the surface energy, and most probably isovector surface energy (also called surface symmetry energy) because heavier nuclei have naturally a larger asymmetry.

References

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