Energy systematics of heavy nuclei in mean field models

B. K. Agrawal\(^1\)\(^*\) and P. -G. Reinhard\(^2\)

\(^1\)Saha Institute of Nuclear Physics Kolkata - 700064, INDIA and
\(^2\)Institut fur Theoretische Physik II, Universitat Erlangen-Nurnberg,
Staudtstrasse 7, D-91058 Erlangen, Germany

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 suggests, 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 (\(\sigma\)), vector-isoscalar (\(\omega\)) and vector-isovector (\(\rho\)) 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 known 513 even-even nuclei 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.

\(^*\)Electronic address: bijay.agrawal@saha.ac.in

Results and Summary

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 from SHF. In each block the most recent parameterizations perform visibly best. This concerns BSR4 in the RMF block and BSk4
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 $\pm 1$ 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 $\pm 1$ 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 under-binding 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
