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Extended energy density functionals and ground-state correlations in nuclei

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Reliable predictions of nuclear properties in exotic nuclei, with controlled theoretical errors, are essential for modelling many stellar processes. In medium heavy and heavy nuclei, the only available approach, able to provide global information on ground-state properties, is based on the one-body degrees of freedom, which in modern formulation takes the form of the energy density functional (EDF) theory. Over the years, methods based on such ideas have proved to be extremely efficient, however, the present-day status thereof is far from being complete. Two elements of the approach are currently intensely studied, namely, construction of schemes that would allow for systematic improvements of the precision and determination of theoretical errors and variances.
In Ref. [1], it was proposed to shift attention and focus of the EDF methods from ground-state bulk properties (e.g. total nuclear masses) to single-particle (s.p.) properties, and to look for a spectroscopic-quality EDFs that would correctly describe nuclear shell structure. Proper positions of s.p. levels are instrumental for good description of deformation, pairing, particle-core coupling, and rotational effects, and many other phenomena. Up to now, methods based on using EDFs, in any of its variants like local Skyrme, non-local Gogny, or relativistic-mean-field [2] approach, were mostly using adjustments to bulk nuclear properties. As a result, shell properties were described poorly. After so many years of investigations, a further increase in precision and predictability of all methods based on the EDFs may require extensions beyond forms currently in use [3,4]. Before this can be fully achieved, it was proposed to first take care of the s.p. properties, and come back to precise adjustment of bulk properties once these extensions are implemented.
Within the standard 12-parameter form of the Skyrme functional [2], an improvement of spectroscopic properties cannot be obtained [3], and extensions of this form seem to be mandatory. One possible way could be the inclusion of density dependence into all the 12 coupling constant of the standard functional [5]. Another one, which was recently proposed in Ref. [4], aims at including gradient corrections up to next-to-next-to-next-to-leading order (N3LO – sixth order). I this talk I describe recent progress and new ideas emerging in the EDF approaches, including the attempts of microscopic derivations from first principles.
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