Nuclear symmetry energy and the breaking of the isospin symmetry: how do they reconcile with each other ?[†]

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The density dependence of symmetry energy is still not understood well enough. A deeper understanding is highly needed, because an accurate characterization of the symmetry energy entails profound consequences for the study of neutron distributions in nuclei along the entire nuclear chart, as well of other properties of neutron-rich nuclei.[1)] The symmetry energy is also of paramount importance for the understanding the properties of compact objects like neutron stars; it directly affects the determination of the radius of a low-mass neutron star.[2)]

The isobaric analog state (IAS) is one of the well-established properties of nuclei that is measured accurately, and it is dominantly sensitive to the isospin symmetry breaking (ISB) in the nuclear medium due to Coulomb interaction.[3)] If there is an inconsistency between the properties of the symmetry energy and our knowledge of the IAS and ISB forces, it is a serious issue. As discussed often, the neutron skin is strongly correlated with the density dependence of the symmetry energy. Therefore, we cannot accept that the values of the neutron skin do not match our understanding of the isospin symmetry, which is one of the basic symmetries of nature, and its breaking.

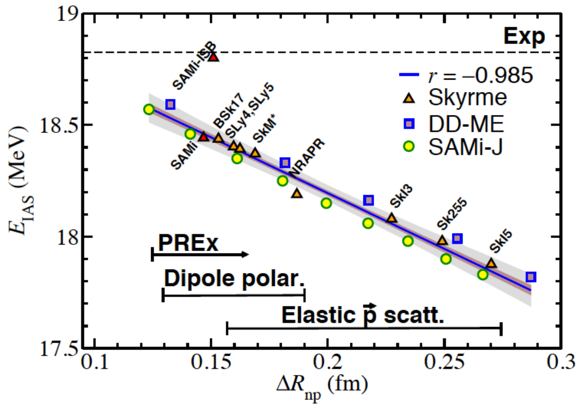

Fig. 1. Energy of the IAS as a function of Δr_{np} with various EDFs. The arrows indicate the experimental results; PRex is obtained from the polarized electron parity violation experiment, Dipole polarizability is the value obtained from the measurement of giant dipole resonances, and elastic p scattering is the data obtained from the polarized proton scattering cross section analysis.

Starting from the prototype SAMi functional, a systematically varied family was generated, by keeping a similar quality of the original fit and varying the values of J and L. In addition, a family based on the systematic variation of J and L with respect to a relativistic mean field (RMF) model with density-dependent meson-nucleon vertices (DD-ME) was also introduced. These functionals provide the values of the neutron skin through the Hartree-Fock (HF) or Hartree solution for the ground-state; in addition, they provide, self-consistently, the IAS energy via the charge-exchange random phase approximation (RPA). The results for the IAS energy, E_{IAS}, as a function of ΔR_{np} are plotted in Fig. 1. The results associated with other Skyrme interactions are also plotted. We found a serious discrepancy of (0.5∼1) MeV between the calculated and experimental E_{IAS} for all EDFs in Fig. 1.

To solve this puzzle, we reconsidered all possible contributions to the IAS energy that have not been considered with sufficient care in self-consistent calculations so far. Then, we proposed a new parametrization SAMi-ISB for Skyrme-like EDF, which reconciles standard nuclear properties (saturation density, binding energy, and charge radii of finite nuclei) with both our current understanding of the density behavior of the symmetry energy and the reproduction of the IAS energy of ^{208}Pb. We have self-consistently included for the first time within the HF+RPA framework, all known contributions that break the isospin symmetry. All of these contributions have been calculated in a model-independent way. We have fixed only two free parameters in the charge symmetry breaking (CSB) and charge independence breaking (CIB) terms, and we have shown that this allows for a good reproduction of the IAS energy of ^{208}Pb without compromising the other properties of nuclear matter and finite nuclei. The calculated results show a fine agreement with the experimental excitation energy of IAS in ^{208}Pb reconciling realistic symmetry energy parameters and the neutron skin as shown in Fig. 1. The energies of IAS in Sn isotopes are also improved by SAMi-ISB.

References
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