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Editorial: Neutron skin thickness in atomic nuclei: current status and recent theoretical, experimental and observational developments

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Editorial on the Research Topic
Neutron skin thickness in atomic nuclei: current status and recent theoretical, experimental and observational developments

Atomic nuclei consist of two types of nucleons with various combinations of their numbers. They are highly intricate, finite quantum many-body systems ruled by strong, electromagnetic, and weak interactions. The thickness of the neutron skin measures how nucleons compose the nucleus, making it one of the most fundamental quantities in nuclear structure. It naturally correlates with the coefficients of the equation of state (EOS) of nuclear matter at the limit of a large nucleon number, which rules astrophysical problems such as the birth, evolution, structure, and death of neutron stars.

The most fundamental problem is obtaining the neutron distribution experimentally, in contrast to that of the proton, which can be precisely determined by electron scattering. The strong interaction probes both neutrons and protons, although their contributions are hard to separate. Another promising approach is to probe the weak charge, which is much larger for neutrons than for protons, although the weak interaction is literally weak and accurate measurements are therefore challenging.

The results of parity-violating electron scattering experiments, which are sensitive to the weak charge, were reported several years ago. The result for ^{208}Pb shows tension with that for ^{48}Ca and with information from other methods and astrophysical observations. The present Research Topic summarizes the current status of a variety of approaches intended to solve this tension.

This Research Topic comprises six contributions, which are primarily theoretical, but also include experimental techniques and observational information. Two contrasting methods are phenomenological mean-field models and *ab initio* calculations starting from fundamental nuclear forces. The former are classified into relativistic and non-relativistic (mainly based on the Skyrme Hartree-Fock (SHF) model) approaches. Miyatsu et al. reviewed the relativistic mean-field (RMF) model, paying close attention to astrophysical observations based on their extensive calculations. SHF is not reviewed in this Research Topic but is utilized in the two original research works by Inakura and Ebata and by Suzuki et al. Miyagi reviewed *ab initio* calculations based on chiral effective field theory, whereas Atkinson and Dickhoff reviewed an alternative method, the dispersive optical model (DOM), whose fundamental feature is the dispersion relation of the self-energy, which is determined from scattering and bound-state experimental data. The mini-review by Tanaka et al. is a collaboration between experimentalists and a theorist focusing on the reaction cross sections of various types at intermediate energies, where experimental techniques and the method of extraction of the neutron skin are discussed. Overall, these diverse contributions encompass a wide range of physical significance, as seen below.

It may be a consensus that the thick skin, if confirmed, of the heavy nucleus ^{208}Pb observed in PREX-2 implies large values of the slope parameter L in the EOS. If ^{48}Ca can be regarded as a small droplet of bulk nuclear matter, its thin skin observed in CREX indicates a smaller L. However, ^{48}Ca may not be heavy enough for the bulk features to dominate. Rather, shell effects may be important. Another point that should be kept in mind is that it is not the L around the saturation density, but rather the stiffness of the EOS at higher densities that determines the observed properties of neutron stars. Furthermore, it is noted that there is still room for improvement in parity-violating electron scattering experiments. For all of the above reasons, there may be several ways to approach the problem.

The first way is to elucidate the extent to which the tension can be alleviated using the current methods. The review by Miyatsu et al. surveyed several parameter sets by calculating ground-state properties of finite nuclei and the EOS of infinite matter. They found a crucial role of the δ meson through δ–N coupling and σ–δ mixing; the former can simultaneously reproduce the skins of ^{208}Pb and ^{48}Ca but unfortunately it cannot satisfy the constraints from neutron stars and relativistic heavy-ion collisions at present. The most important feature of Miyagi's *ab initio* calculation is that the uncertainty at each step of the calculation is quantified. The result for ^{208}Pb shows that the tension remains. In contrast, the DOM by Atkinson and Dickhoff fully took experimental information into account to determine the self-energy and to calculate the neutron skin thickness. Their results are consistent with the ^{208}Pb data but not with the ^{48}Ca data.

The second way is to examine other quantities to identify the problem. Based on another mean-field model, SHF, and on the random phase approximation, Inakura and Ebata investigated isospin splitting in low-energy electric dipole ($E1$) states and they found that the sum of the isoscalar strengths in the unstable nucleus ^{132}Sn strongly correlates with L. This is interesting in that not only the skin, which is a ground-state property, but also some types of excitations strongly correlate with L. Suzuki et al. argued that the point-nucleon distributions, $\rho_{\rm n}(\mathbf{r})$ and $\rho_{\rm p}(\mathbf{r})$ can be precisely determined by consistently analyzing both electron- and proton scattering. Their second moments, $\langle r^2\rangle_{\rm n}$ and $\langle r^2\rangle_{\rm p}$, are the mean square radii, and the difference between their square roots defines the skin thickness. The key factor is that the fourth moment of the charge distribution, $\langle r^4\rangle_{\rm c}$, contains the contribution from $\langle r^2\rangle_{\rm n}$, although $\langle r^2\rangle_{\rm c}$ does not depend on $\langle r^2\rangle_{\rm n}$ and therefore $\langle r^2\rangle_{\rm p}$ can be extracted from it. It is noted here that the present status of the experimental and theoretical studies of the charge distribution is briefly summarized in the review by Miyagi.

The third way is to study experimentally not only stable but also unstable nuclei as extensively as possible across the nuclear chart. At intermediate incident energies of approximately 100–1,000 MeV/nucleon, the reaction mechanism becomes simple and the reaction and/or interaction cross sections directly determine the matter radius. Since experiments can be performed even with low beam densities, this method is suitable for unstable nuclei. The obtained matter radius determines the neutron skin thickness by combining with the proton radius extracted from other methods. In addition, new ways of determining the skin thickness solely from cross sections were discussed by Tanaka et al.

There are many other methods and strategies that are not included in this limited Research Topic. We believe that we will be able to gain a deep understanding of the nuclear many-body systems as soon as we overcome the problems addressed in the present Research Topic.

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