Mean-square radius of the neutron distribution and skin thickness derived from electron scattering†

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To the authors' knowledge, this is the first study to deduce the neutron distribution from electron scattering data in the history of nuclear physics.[1]

The question how neutrons are distributed in nuclei has been a longstanding problem. Although it is one of the most fundamental problems in nuclear physics, the neutron distribution has not been well determined yet, because there is no simple and reliable method to explore it experimentally.[2] In contrast to the neutron distribution, the proton distribution has been widely investigated through the nuclear charge density deduced from electron scattering.[3] Electron scattering is an unambiguous and unique tool to examine the charge distribution, because the electromagnetic interaction is well understood and allows reactions that do not disturb the nuclear ground-state properties.[4]

So far, electron scattering has been believed to be useful for the study of the only proton distribution and has not been discussed in the context of the neutron distribution in nuclei.[4] The SCRIT in RIKEN[5] also constructed with the primary objective of exploring the proton distribution in unstable nuclei, although the neutron distribution plays a crucial role in the stability of neutron-rich nuclei. Such dogma is based on the fact that the neutron charge density is approximately 1% of the total nuclear charge density and oscillates as a function of the nuclear coordinate, yielding zero integrated charge.

Recently, the precise expressions for the moments of the nuclear charge density were derived according to relativistic quantum mechanics.[6] It has been shown that the second-order moment of the nuclear charge density(R_c^2) is dominated by the mean-square radius (msr) of the point proton distribution (R_p^2), while the nth (≥ 4)-order moment depends on the (n-2)th-order moment of the point neutron distribution also. For example, the fourth-order moment (Q_c^4) of the charge density depends on the msr of the point neutron distribution (R_n^2). The contribution of R_n^2 to Q_c^4 is dominated by the number of excess neutrons.

The present authors have analyzed experimental data of R_c^2 and Q_c^4 deduced from the electron scattering off ^{40}Ca, ^{48}Ca, and ^{208}Pb, which are available at present.[3] First, using relativistic and non-relativistic mean field models accumulated over the last 50 years in nuclear physics, the linear relationship between the various moments are explored with the use of the least-squares method. Next, from the intersection of the predicted least-square lines and the lines of the experimental value for R_c^2 or Q_c^4 , the values of R_n^2 together with R_p^2 of those nuclei have been estimated. They are obtained within 1% accuracy, including both experimental error and the standard deviation of the least-square lines.[1]

This paper opens a new possibility of electron scattering as a clean and practical probe to extract neutron density information. As the contributions from the neutron density to the charge density are expected to increase in neutron-rich nuclei, the new electron scattering facilities in the world[5] which are led by the SCRIT[7] would make the forthcoming study of unstable nuclei more efficient and stimulating, both experimentally and theoretically.

References
1) H. Kurasawa, T. Suda, T. Suzuki, Prog. Theor. Exp. Phys. **2021**, 013D02 (2021).
2) M. Thiel *et al.*, J. Phys. G **46**, 093003 (2019).
3) H. De Vries, C. W. De Jager, C. De Vries, Atom. Data Nucl. Data Tables **36**, 495 (1987).
4) T. deForest, J. D. Walecka, Adv. Phys. **15**, 1 (1966).
5) T. Suda, H. Simon, Prog. Part. Nucl. Phys. **96**, 1 (2017).
6) H. Kurasawa, T. Suzuki, Prog. Theor. Exp. Phys. **2019**, 113D01 (2019).
7) K. Tsukada *et al.*, Phys. Rev. Lett. **118**, 262501 (2017).

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