Nuclear surface diffuseness revealed in nucleon-nucleus diffraction†

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A systematic study of the nuclear surface density of neutron-rich nuclei is interesting, as it reveals the neutron number dependence of the nuclear structure dominated by nuclear dynamics at around the nuclear surface. The study can also be extended to understand the properties of the equation of state of asymmetric nuclear matter. However, it is difficult to probe the neutron density by using traditional electron scattering. In this paper, we use a proton target as a probe of the surface density. Extended systematic studies have shown that it is advantageous to use proton to study the neutron and proton radii because it has more sensitivity to the neutrons at low-incident energy.[1,2] To know more than the nuclear radii, we study the proton-nucleus elastic scattering, focusing on the reactions of small scattering angles up to a few diffraction peaks.

Here, we employ the optical-limit approximation of the Glauber model. As the input to the theory, a two-parameter Fermi (2 pF) density, $\rho(r) = \frac{\rho_0}{1+\exp\left(\frac{r-R}{a}\right)}$, is assumed. The parameter R is chosen to give the same root-mean-square (rms) radius with several choices of a. By calculating differential elastic scattering cross sections (DECS), it is found that the first peak position does not change and that its magnitude increases with smaller diffuseness (sharper surface). The magnitude of the DECS at the first peak position must have information on the nuclear surface.

We perform a "numerical experiment" to deduce the nuclear "diffuseness" from the reaction data. We have the DECS obtained from the realistic densities, the Skyrme-Hartree-Fock (HF) + BCS method used in Refs. 2) and 3). Regarding the DECS used as experimental data, we determine R and a in such a way that the DECS with the 2 pF density matches the first peak position and its magnitude of the DECS obtained by the HF+BCS density. The extracted a values are displayed in Fig. 1. We can clearly see the isotope dependence of the nuclear surface, indicating shell evolution, weak binding, and nuclear deformation, which crucially change the density profile at around the nuclear surface.[3] We find that the extracted a values have a robust structure information that is independent of the choice of the incident energy.

To extract detailed structure information of unstable nuclei, separation of proton and neutron diffuseness is important because neutron diffuseness is expected to be more sensitive to the ground-state structure of neutron-rich isotopes as it is dominated by the neutron motion at the nuclear surface. We investigate the possibility of utilizing the incident energy dependence of the nucleon-nucleon total cross sections.[1,2] Again, we perform a numerical experiment. We respectively assume 2 pF densities for protons and neutrons and determine these four parameters to reproduce the first peak positions and their DECS at low and high incident energies. We calculate the diffuseness parameters and rms radii of the protons and neutrons for ^{120}Sn, ^{208}Pb, and neutron-rich ^{132}Sn with several sets of two incident energies among 200, 300, 550, and 800 MeV. For ^{120}Sn and ^{208}Pb, the extracted diffuseness parameters are scattered around 0.4–0.6 fm depending on the incident energies chosen, though the rms radii are converged within ~0.5%. In such cases where the proton and neutron surfaces are located at almost the same position, the separation of the proton and neutron surface profiles might be difficult, whereas in the case of ^{132}Sn, all the extracted values are consistent with each other within 0.003 fm for protons and neutrons.

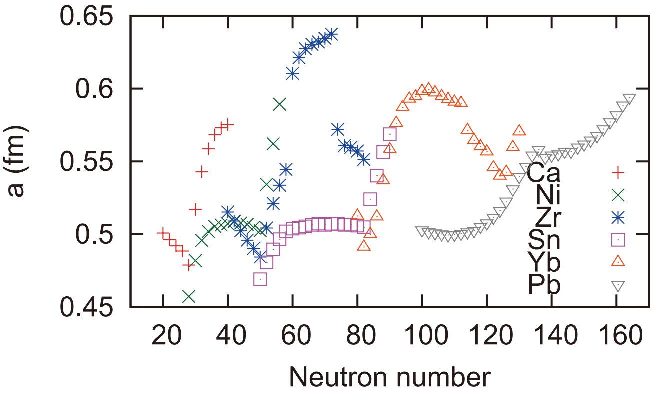

Fig. 1. Nuclear "diffuseness" extracted from the "numerical experiment" at an incident energy of 550 MeV.

In summary, we have performed a numerical experiment using the theoretically obtained DECS of high-energy nucleon-nucleus scattering based on the Glauber model starting from the nucleon-nucleon total cross sections. We have shown that first diffraction peak reflects the nuclear density profile at around the nuclear surface, and have proposed a way to quantify it with the diffuseness parameter of the 2 pF function, which can be determined uniquely. This method is advantageous for application to studies of unstable nuclei since the experimental data is limited to forward angles in the inverse kinematics. This can also be useful for extracting the information of the proton and neutron surfaces, although the separation of the proton and neutron surfaces may be possible only for such neutron (proton)-rich systems in which the surfaces of the proton and neutron surfaces are well separated.

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