Study of proton and neutron density distributions observed via proton elastic scattering at 200 and 300 MeV

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A systematic study of the nucleon density distributions of finite nuclei is important for understanding the isospin dependence of the nuclear many-body system. For example, the neutron skin thicknesses are known to be strongly correlated with the density-dependent term of the symmetry energy, and the isospin-dependent term of the nuclear equation of state.

In previous works,[1,2] we have succeeded in extracting the neutron density distributions of stable nuclei such as Sn and Pb isotopes via proton elastic scattering. At the same time we have launched a new project aimed at measuring the Elastic Scattering of Protons with RI beams (ESPRI) with the purpose of the extraction of proton and neutron density distributions of unstable nuclei. We have newly developed and tested unique devices for the ESPRI measurements at NIRS-HIMAC in Chiba and GSI in Germany.[3,4] Finally, we have successfully performed the ESPRI experiment at RIBF in April, 2013.[5]

Unlike the case of stable nuclei, however, we have no information on the nuclear charge densities of unstable nuclei. Thus, we have proposed a new method to extract proton and neutron densities via two-energy proton elastic scattering. This method is based on the large difference between the energy dependences of the p-p and p-n interactions. Recently, we performed an experiment to demonstrate this new method using real data of Zr isotopes. In this report, we show the preliminary results of ^{90}Zr only. For other isotopes (^{92,94}Zr), the analysis is still ongoing.

The experiment was performed at RCNP, Osaka University. Polarized proton elastic scattering from ^{90,92,94}Zr and ^{58}Ni at 200 and 300 MeV was measured by using the Grand Raiden magnetic spectrometer.[6] Figure 1 shows the angular distributions of cross sections ($d\sigma/d\Omega$) and the analyzing powers (A_y) of ^{90}Zr($\vec{p}$,p) at 200 and 300 MeV and of ^{58}Ni($\vec{p}$,p) at 200 MeV. The red lines denote the result of relativistic impulse approximation (RIA) with relativistic-Hartree (RH) densities. The ^{58}Ni data was used to determine the effective interaction at 200 MeV (solid lines). Using the effective interaction, the proton and neutron densities of ^{90}Zr were simultaneously searched and the results are denoted by the solid lines in Fig. 1 and 2. The proton and neutron densities can be separately and simultaneously determined by the new method. The extracted proton and neutron radii of ^{90}Zr are 4.210(20) and 4.300(17) fm, respectively. The extracted proton radius is very consistent with that of 4.198(1) fm, which is derived from the charge radius determined via the combined analysis of electron elastic scattering and muonic atom X-rays data.[7]

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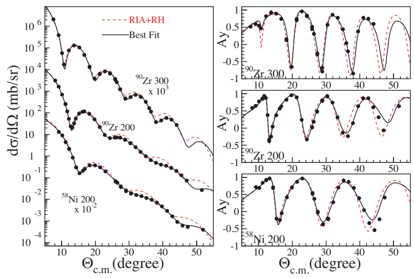

Fig. 1. Obtained data of $d\sigma/d\Omega$ and A_y of ^{90}Zr at 200 and 300 MeV and of ^{58}Ni at 200 MeV. The black solid lines show the fitting results while the red dashed lines are RIA calculations with RH densities.

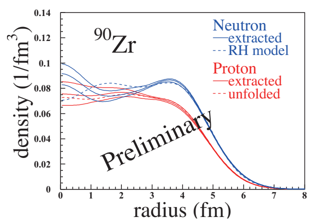

Fig. 2. Extracted proton and neutron densities, denoted by solid red and blue lines, respectively. While upper and lower lines show the error envelopes due to the experimental errors, middle lines are the best-fit results. The red dashed line shows the proton density by unfolding the nuclear charge density. Blue dashed line shows the same by the RH model calculation.

References

1) S. Terashima *et al.*: Phys. Rev. C **77**, 024317 (2008).
2) J. Zenihiro *et al.*: Phys. Rev. C **82**, 044611 (2010).
3) Y. Matsuda *et al.*: Phys. Rev. C **87**, 034614 (2013).
4) S. Terashima *et al.*: GSI Scientific Report, 148 (2010).
5) S. Terashima *et al.*: in this report.
6) M. Fujiwara *et al.*: Nucl. Instr. Meth. A **422**, 484 (1999).
7) I. Angeli: At. Data Nucl. Data Tables **87**, 185 (2004).