Neutron Density Distributions Deduced from Antiprotonic Atoms

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Large differences between neutron and proton radii are expected to characterize the nuclei at the border–of–stability line, an important future domain of nuclear structure studies. Therefore the information on these quantities for stable nuclei is a convenient starting point for studies of more exotic nuclei. However, whereas the peripheral proton distributions are well known for stable nuclei from electromagnetically interacting probes, the situation is much more unclear for neutron distributions, where 20–40% errors of the mean square radii are a rule rather than an exception. Therefore, all new experimental information on these distributions is of a great interest.

In this article a ten–years effort of the Warsaw–Munich collaboration aiming at the determination of the extent and composition of the nuclear periphery using antiprotons from the LEAR facility at CERN is summarized. The differences Δr_{np} between the root mean square radii of neutron and proton distributions were determined for 26 nuclei spanning the mass range from 40 to 238. Two experimental methods were applied: analysis of the antiproton annihilation residues one mass unit lighter than the target mass by nuclear spectroscopy and the measurement of strong interaction effects on antiprotonic X-rays. The conclusion is that, under the assumption of two-parameter Fermi neutron and proton distributions, only the neutron diffuseness is increasing in neutron rich nuclei and not their half-density radius. A linear relationship between Δr_{np} and the asymmetry parameter $\delta = (N - Z)/A$ was established as shown in the Figure ($\Delta r_{np} = -0.04 + 0.90 \cdot \delta$ fm).

The experimentally determined Δr_{np} values were compared with the previously gathered data using hadronic probes and with the mean field calculations. The antiprotonic Δr_{np} value for ^{208}Pb (0.15 ± 0.02 fm) is in excellent agreement whit the average value of six previous hadronic results and with Hartree-Fock calculations using SkP, Sly4, SkX and Gogny force. Relativistic mean field calculations using NL1 and NL3 force are substantially larger than the ^{208}Pb experimental value.

Presently a number of projects for the continuation of the antiprotonic X-ray studies using radioactive beams are proposed.