NEUTRON AND PROTON DISTRIBUTION IN NUCLEI IN RELATIVISTIC MEAN FIELD THEORY* **

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Differences between neutron and proton distributions were investigated for β-stable nuclei and for chains of isotopes and isotones up to drip line nuclei. The relativistic mean field theory with the parameter set NL-3 was used in calculations. Dependence of neutron and proton radius and mean density on relative neutron excess $I = (N-Z)/A$ was found. Different deformations of neutron and proton matter were noticed.

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Neutrons and protons in nuclei are not distributed identically. This is caused by different numbers of these particles and different interactions. The most obvious consequences are differences in radii and mean density of proton and neutron distribution. On the other hand, neutron and proton matter may have slightly different deformations.

The relativistic mean field theory with nonlinear Lagrangian defined in [1] was used to calculate nuclear sizes. The set of parameters NL-3 [2] was chosen, considered as the best one for describing nuclei over all the periodic table [3].

From liquid drop model the nuclear radius depends on the mass number A:

$$R_0 = 1.2\, A^{1/3} \text{ fm}. \tag{1}$$

But a more precise analysis of the experimental data shows that the nuclear charge radius depends also on the relative neutron excess $I = (N-Z)/A$ [4]:

$$R_0^{ch} = 1.256 \left(1 - 0.202 \frac{N-Z}{A}\right) A^{1/3} \text{ fm}. \tag{2}$$

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Results obtained from relativistic mean field calculations give similar formulae for proton and neutron radii [3, 6]:

$$\begin{aligned} R_0^p &= 1.235\left(1-0.15\frac{N-Z}{A}\right)A^{\frac{1}{3}}\ \text{fm} \\ R_0^n &= 1.212\left(1+0.21\frac{N-Z}{A}\right)A^{\frac{1}{3}}\ \text{fm}\,. \end{aligned} \quad (3)$$

The calculations were performed for the β-stable nuclei with $A \geq 40$ and the chains of isotopes with $Z = 50$, 56, 82, 94 and isotones with $N = 50$, 82. In Fig. 1, proton and neutron radii for the chains of isotopes and isotones are compared with the results of the formulae (3).

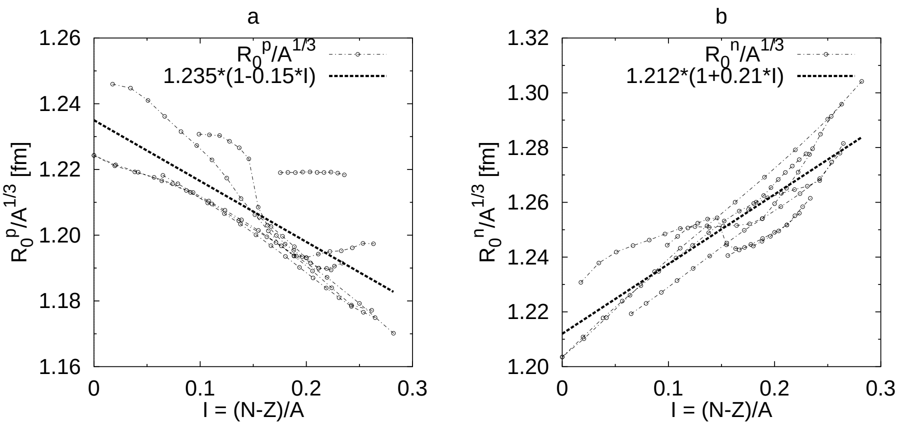

Fig. 1. Proton (a) and neutron (b) radius as a function of $I = (N-Z)/Z$ for a few chains of isotopes and isotones. Dashed lines correspond to the formulae (3) (from [5]).

Mean density of protons and neutrons defined as

$$\langle\rho\rangle_{n,p} = \frac{\int d^3r\ \rho^2_{n,p}(\boldsymbol{r})}{\int d^3r\ \rho_{n,p}(\boldsymbol{r})} \quad (4)$$

also depends on the relative neutron excess $I = (N-Z)/A$. In Fig. 2, the mean density of the same chains of isotopes and isotones as in Fig. 1 are plotted. The dashed lines follow the formulae for average densities

$$\begin{aligned} \langle\rho\rangle_p &= 0.058\left(1-0.63\frac{N-Z}{A}\right)\ \text{fm}^{-3}\,, \\ \langle\rho\rangle_n &= 0.061\left(1+0.27\frac{N-Z}{A}\right)\ \text{fm}^{-3}\,. \end{aligned} \quad (5)$$

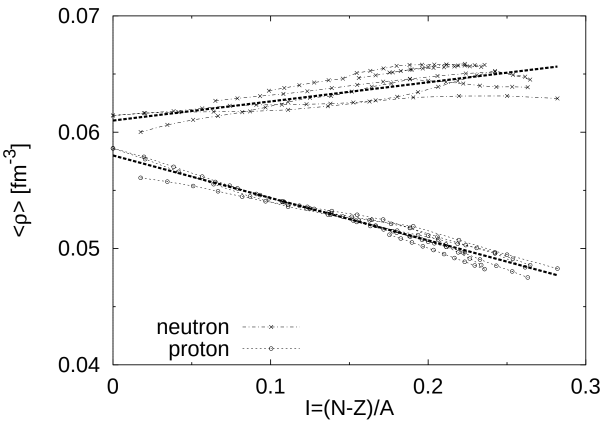

Fig. 2. Mean density of neutrons (crosses) and protons (circles). Dashed lines correspond to the formulae (5).

The differences in deformations were previously investigated in [7] using many nuclear models. It was found there that neutron and proton matter deformations in the same nuclei differ up to 10 %. In Fig. 3, proton and neu-

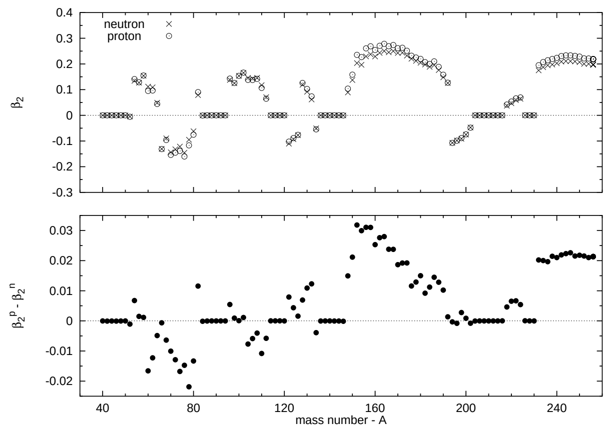

Fig. 3. Neutron (crosses) and proton (circles) deformations (top) and the difference between them (bottom) for β-stable nuclei.

tron deformations are shown for β-stable nuclei with $A \geq 40$. Deformation parameter β_2 is defined as:

$$\beta_2^{n,p} = \sqrt{\frac{4\pi}{5}} \frac{\langle Q_2 \rangle_{n,p}}{\langle Q_0 \rangle_{n,p}}\,, \tag{6}$$

where $\langle Q_2\rangle_{n,p} = \left\langle 2r^2_{n,p}P_2(\cos\theta)\right\rangle$, $\langle Q_0\rangle_n = N\left\langle r^{\,2}\right\rangle_n$ and $\langle Q_0\rangle_p = Z\left\langle r^{\,2}\right\rangle_p$ are quadrupole and monopole moments for neutrons and protons. In the bottom part of Fig. 3 differences between the proton and neutron deformation parameter β_2 are plotted for the same nuclei. In Fig. 4, one can see the same quantities for chains of isotopes $_{56}$Ba , $_{82}$Pb and $_{94}$Pu.

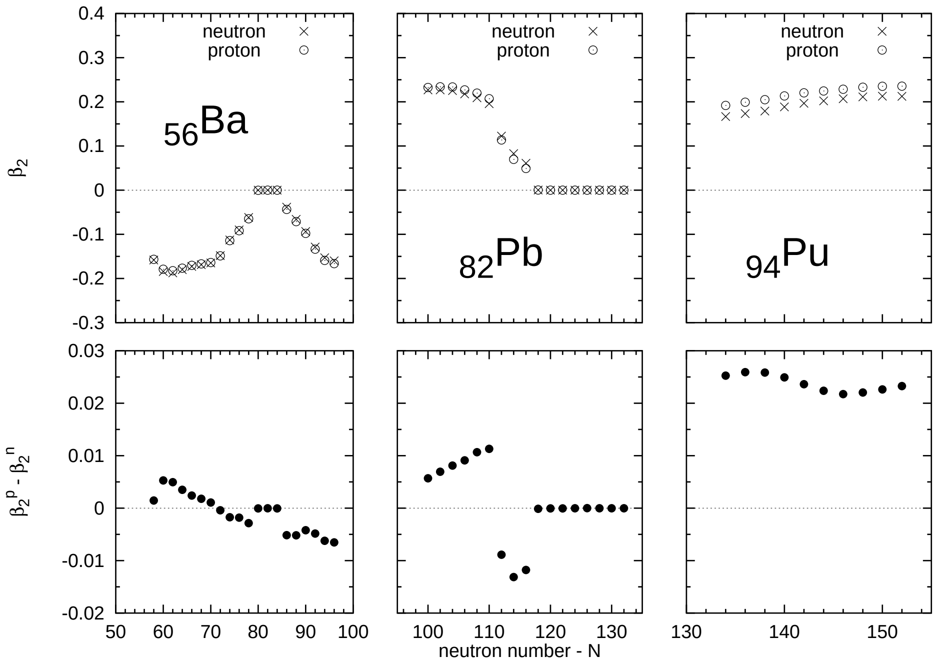

Fig. 4. The same as in Fig. 3 but for chains of isotopes $_{56}$Ba , $_{82}$Pb and $_{94}$Pu.

In the most cases the neutron matter is more spherical then the proton one. This is caused mainly by the strong Coulomb repulsion of protons. The difference in β_2 does not exceed 0.04. It is worth to notice that, as far as spherical nuclei are considered, both proton and neutron matter have spherical shape.

Concluding, the neutron and proton distributions in nuclei are not identical. The main differences were found in the mean density and radius. A simple dependence on the relative neutron excess was found for these quantities (3), (5). In more precise calculations the difference in deformation between proton and neutron distributions should be also considered.

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