THE NEUTRON AND PROTON DENSITY DISTRIBUTIONS WITHIN THE HFB CALCULATION WITH THE GOGNY FORCE* **

B. Nerlo-Pomorska, K. Pomorski

Institute of Physics, Maria Curie-Skłodowska University
pl. M. Curie-Skłodowskiej 1, 20-031 Lublin, Poland

and J.F. Berger

Commissariat á L'Energie Atomique, Service de Physique Nucléaire,
B.P. 12, 91680 Bruyères-le-Châtel, France

(Received November 2, 2000)

The size and shape of the neutron and proton density distributions obtained in the Hartree–Fock–Bogoliubov (HFB) calculations with the Gogny force D1S are investigated. The radial density distributions at distances far from nuclear surface are analyzed. Significant differences in the multipole deformations of neutron and proton densities along the fission paths are found. The effect of an additional constraint imposing the same size and deformation of neutrons and protons distributions on barrier heights is studied.

PACS numbers: 21.24.Dr, 21.30.Fe, 21.60.Jz

For many years one has assumed that protons and neutrons are almost equally distributed in a nucleus. Using the macroscopic–microscopic method [1] to calculate the potential energy of nuclei the same equilibrium deformations were used not only to the liquid drop part but also for proton and neutron microscopic terms. Already in [2] it was noticed that in order to obtain the same multipole moments for the macroscopic and the microscopic densities, different deformations of the mass distribution and the single-particle potential should be used.

* Presented at the XXXV Zakopane School of Physics "Trends in Nuclear Physics", Zakopane, Poland, September 5–13, 2000.

** The work was partially sponsored by the Polish State Committee for Scientific Research (KBN) No. 2P 03B 115 19.

Self-consistent calculations (see *e.g.* [3–6] have shown that in heavier nuclei, especially those far from β stability, the neutron and proton density distributions have different sizes and deformations. In some nuclei a thick neutron skin [6] or neutron halo effects [7, 8] were predicted. The theoretically foreseen effects were difficult to prove unless the experimental neutron radii and densities appeared. While the charge distributions in nuclei were broadly measured by the mean square radii shifts and electric quadrupole moments [9, 10] the neutron peripheral distributions have been only lately deduced from the antiproton annihilation on the outer orbits of a nucleus [11].

The Hartree–Fock–Bogoliubov self-consistent method with the finite range effective nucleon–nucleon force of Gogny [12] is very successful in reproducing many properties of nuclei. Our aim was to examine the proton and neutron densities distribution obtained in this model. The neutron halo effect was studied for several nuclei in [8] by the HFB method with the D1S Gogny force within the spherical approximation. Now we would like to examine the effect of the ground state deformation on the neutron halo factors.

In the left-hand side of Fig. 1 is plotted the logarithm of the ratio of the neutron to proton densities of ^{232}Th as a function of the distance from the center of nucleus. Curve a is obtained for the spherical shape of nucleus (as in Ref. [8]) while b and c are at the equilibrium deformation. The distribution in the equatorial plane b is very close to the spherical one, while the densities evaluated along the symmetry axis c differ significantly from the spherical case. The antiproton caught on a Bohr orbit polarises the system

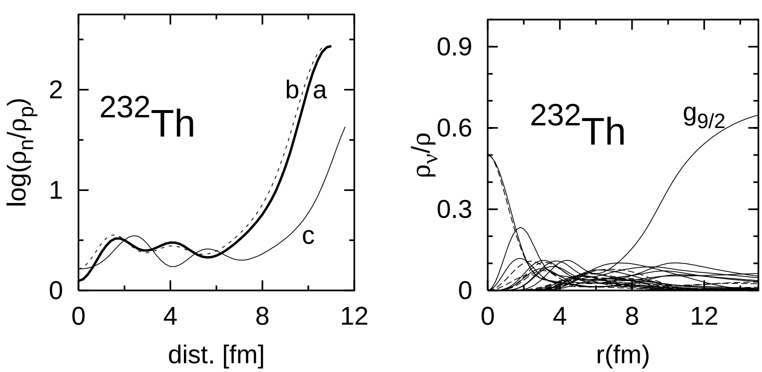

Fig. 1. The radial dependence of the logarithm of the neutron to proton densities ratios for the spherical case a and in the equatorial plane b and along the symmetry axis c of the deformed nucleus ^{232}Th (l.h.s). The contribution of the single orbitals to the total density are presented in the r.h.s. part of the figure.

and, classically speaking, the symmetry axis of nucleus becomes perpendicular to the plane of the antiproton orbit, which corresponds to the energy minimum. This result means that the deformation effect on the neutron halo factor, determined mainly by the ratio ρ_n/ρ_p in the vicinity of the antiproton orbital, should be rather small. One has to remind that the peripheral density distribution in nuclei is mainly determined by a single orbital. This can be seen in the right-hand side part of Fig. 1, where the ratio of the single-particle densities (ρ_ν) to the total density (ρ) is plotted. The solid lines represent the neutron densities while the dashed ones are those for protons.

The difference between the neutron and proton distributions along the fission path was studied in Ref. [13] in the HFB approach with the D1S Gogny force. We discuss the effect of an additional condition ensuring the same shape and size for proton and neutron distributions, as assumed in the macroscopic-microscopic Strutinsky method, on the fission barrier height. In Fig. 2 we can see that for ^{232}Th the Strutinsky method could lead to an ar-

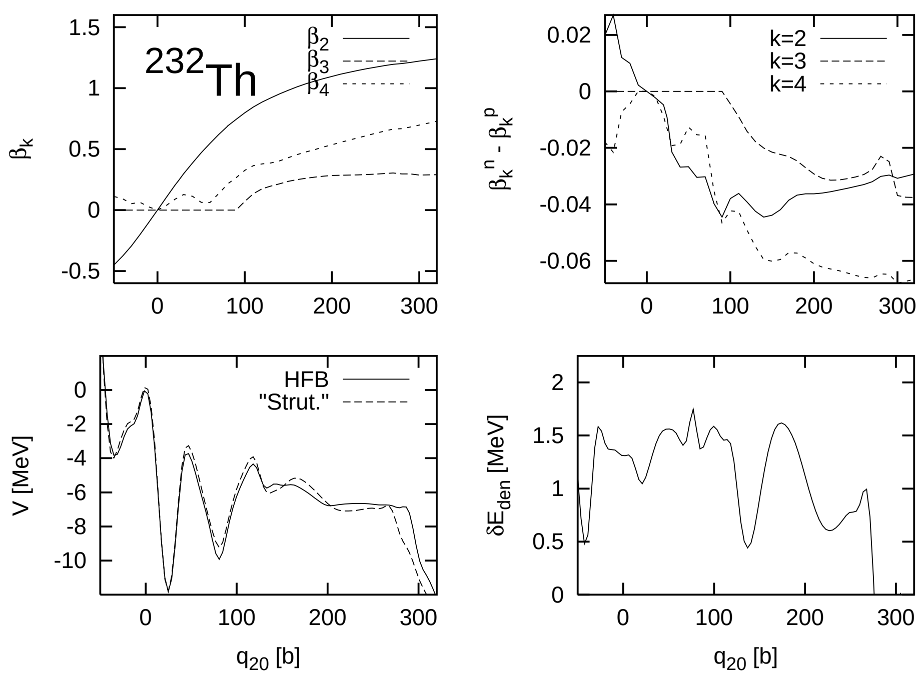

Fig. 2. Total density deformations (β_k) and their differences for neutron and proton distributions ($\beta_k^n - \beta_k^p$) are drawn in the upper figures as functions of the quadrupole deformation q_{20}. The HFB and Strutinsky energy as well as the effect of different sizes and shapes of neutron and proton distributions on the HFB energy ($\delta E_{\rm den}$) along the fission path of ^{232}Th are shown in the lower part of the figure.

tificial increase of the fission barrier by about 1 MeV. This result means that the effect of different ρ_p and ρ_n has to be taken into account in macroscopic-microscopic methods.

The potential energy of nucleus should therefore be evaluated using the following formula:

$$E_{\rm HFB} \approx E_{\rm Strut} = E_{\rm macr}(\bar{\rho}_p, \bar{\rho}_n) + \delta E_p^{\rm micr}(\rho_p) + \delta E_n^{\rm micr}(\rho_n)\,, \qquad (1)$$

where $\bar{\rho}$ is the average density put into the macroscopic contribution (one of the available liquid drop like formulas or the new one developed especially for this method). The microscopic shell and pairing corrections for protons $\delta E_p^{\rm micr}$ should depend on the proton density distribution, while the neutron one $\delta E_n^{\rm shell}$ should depend on the neutron density distribution.

REFERENCES

[1] V.M. Strutinsky, *Yad. Fiz.* **36**, 614 (1966).

[2] B. Nerlo-Pomorska, K. Pomorski, *Nukleonika* **22**, 289 (1977).

[3] A. Baran, J.L. Egido, B. Nerlo-Pomorska, K. Pomorski, P. Ring, L.M. Robledo, *J. Phys. G* **21**, 657 (1995).

[4] J. Dobaczewski, W. Nazarewicz, T. Werner, *Z. Phys.* **A354**, 27 (1996).

[5] K. Pomorski, P. Ring, G.A. Lalazissis, A. Baran, Z. Łojewski, B. Nerlo-Pomorska, M. Warda, *Nucl. Phys.* **A624**, 349 (1997).

[6] M. Warda, B. Nerlo-Pomorska, K. Pomorski, *Nucl. Phys.* **A635**, 484 (1998).

[7] A. Baran, K. Pomorski, M. Warda, *Z. Phys.* **A357**, 33 (1997).

[8] B. Nerlo-Pomorska, K. Pomorski, J.F. Berger, J. Décharge, *Eur. Phys. J.* **A8**, 19 (2000).

[9] E.W. Otten, *Treatise on Heavy Ion*, ed. D.A. Bromley, Science, New York 1989, **8**, p. 317.

[10] G. Fricke, C. Bernhardt, *At. Data Nucl. Data Tables* **60**, 177 (1995).

[11] P. Lubiński, J. Jastrzębski, A. Trzcińska, W. Kurcewicz, H.J. Hartman, W. Schmid, T. von Egidy, R. Smolańczuk, S. Wycech, *Phys. Rev.* **C57**, 2962 (1998).

[12] J.F. Berger, M. Girod, D. Gogny, *Nucl. Phys.* **A438**, 236 (1984).

[13] J.F. Berger, K. Pomorski, *Phys. Rev. Lett.* **85**, 30 (2000).