SINGLE-NUCLEON DENSITIES IN SUPERHEAVY NUCLEI*

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Radii and diffuseness parameters of heavy and superheavy nuclei are analyzed for spherical and axially deformed shapes within the Skyrme–Hartree–Fock+BCS theory with zero-range pairing force.

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1. Introduction

Nuclear moments provide stringent tests of nuclear models. There exist many data on charge distributions of nuclei close to the β stability line [1,2] and rather limited information on neutron distributions (*cf.* Ref. [3] for a review). In this work, we investigated properties of heavy and superheavy nuclei with 92< Z <128 and 132< N <188. We have first determined self-consistent single-particle density distributions using the Hartree–Fock+BCS

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model with the Skyrme interaction SLy4 and the same zero range pairing force as in a previous study of superheavy nuclei [4, 5]. These density distributions then have been analyzed using the Helm model [6] in order to extract physical parameters, such as the density radius and surface diffuseness. The mean-field calculations have been performed for spherical and axially deformed nuclear shapes.

2. Deformed Helm model

The deformed Helm model has been used to analyze the single-nucleon density distributions. The density radius and the diffuseness parameter are determined from the form factor of the density distribution,

$$F(\boldsymbol{q}) = \int \rho(\boldsymbol{r})\, e^{i\boldsymbol{q}\boldsymbol{r}}\, d^3\boldsymbol{r}. \tag{1}$$

For axially symmetric density distributions $\rho(\boldsymbol{r})$, the corresponding form factor $\mathrm{F}(\boldsymbol{q})$ is also axially symmetric.

There are various ways to characterize nucleonic densities. In this work, we have used the Helm model in which the density is approximated by the convolution of a sharp-surface density with radius $R(\theta)$ with a Gaussian profile function $f_{\mathrm{G}}(r)$

$$\rho^{(\mathrm{H})}(\boldsymbol{r}) = \int d^3\boldsymbol{r'} f_{\mathrm{G}}(\boldsymbol{r}-\boldsymbol{r'})\rho_0 \Theta(R(\theta) - |\boldsymbol{r'}|)\,, \tag{2}$$

where

$$f_{\mathrm{G}}(r) \;=\; \frac{1}{(2\pi)^{3/2}\sigma^3}\,\mathrm{e}^{-\frac{r^2}{2\sigma^2}}\,, \tag{3}$$

$$R(\theta) \;=\; c(\beta)\, R_0 \left[1 + \sum_l \beta_l Y_{l0}(\theta)\right]. \tag{4}$$

The radius R_0 in Eq. (4) is the diffraction (box equivalent) radius, and $\{\beta_l\}$ denotes the set of axial deformation parameters. The folding width σ determines the surface thickness. The quantity $c(\boldsymbol{\beta})$ in Eq. (4) guarantees that the volume conservation condition is met. Since the Helm density $\rho^{(\mathrm{H})}(\boldsymbol{r})$ must be normalized to the number of particles N, the parameter ρ_0 is given by

$$\rho_0 = \frac{3N}{4\pi R_0^3}. \tag{5}$$

The advantage of the Helm model comes from the fact that folding becomes a simple product in the momentum space. Using the well-known identity

$$e^{i\boldsymbol{q}\boldsymbol{r}} = 4\pi \sum_{l=0}^{\infty} \sum_{m=-l}^{l} i^l j_l(qr) Y^*_{lm}(\hat{\boldsymbol{q}}) Y_{lm}(\hat{\boldsymbol{r}}), \tag{6}$$

one can rewrite Eq. (1) for the Helm density as follows

$$F^{(\mathrm{H})}(\boldsymbol{q}) = \sqrt{4\pi} \sum_{l=0}^{\infty} G_l(q)\, Y^*_{l0}(\hat{\boldsymbol{q}}), \tag{7}$$

where

$$G_l(q) = e^{-\frac{\sigma^2 q^2}{2}} i^l 4\pi \int j_1(qr) Y_{l0}(\hat{\boldsymbol{r}}) \rho_0 \Theta\left(R(\theta) - |\boldsymbol{r}|\right) d^3\boldsymbol{r} \tag{8}$$

are the coefficients of the expansion of the axially symmetric form factor in terms of spherical harmonics. In the spherical case, the coefficient $G_l(q)$ is different from 0 only for $l = 0$. The first zero of $G_0(q)$ is uniquely determined by the radius R_0 and the deformation parameters β_l. In the spherical case, the first zero of $G_0(q)$ depends only on R_0 [7]. (For more discussion of the deformed Helm model, see Ref. [8].) In this work, we have applied the following procedure to determine the nuclear radius and the surface thickness.

First we search for the first zero $q_0^{(R)}$ of the monopole part of the form factor, $G_0(q)$. We then take a constant density surface $R^{(R)}(\theta)$ corresponding to $\rho_c = \frac{1}{2}\rho(0)$ and determine its parameters according to the formulae

$$R_0 c(\beta) = \frac{\int_0^\pi R^{(R)}(\theta) Y_{00} \sin\theta d\theta}{\int_0^\pi Y_{00} \sin\theta d\theta}, \tag{9}$$

$$\beta_l = \frac{\int_0^\pi R^{(R)}(\theta) Y_{l0} \sin\theta d\theta}{R_0 c(\beta)}. \tag{10}$$

Substituting the parameters R_0, β_l into Eq. (3) we determine the first zero $q_0^{(\mathrm{H})}$ of $G_0(q)$ and compare it to $q_0^{(R)}$. If they are not equal, the quantity ρ_c is varied until the condition

$$q_0^{(\mathrm{H})} = q_0^{(R)} \tag{11}$$

is achieved. The surface thickness parameter σ can be computed by comparing the values of the microscopic and Helm monopole form factors at the first maximum q_m [7]:

$$\sigma^2 = \frac{2}{q_m^2} ln \frac{G_0^{(\mathrm{H})}(q_m)}{G_0^{(R)}(q_m)}. \tag{12}$$

3. Results

The values of R_0 and σ obtained for nuclei ranging from U to $Z = 128$ are plotted as a function of N in Figs. 1 (proton densities) and 2 (neutron densities). We have considered deformed (portions (a) and (c) of the figures) and spherical (parts (b) and (d)) configurations. Due to self-consistency, r_0

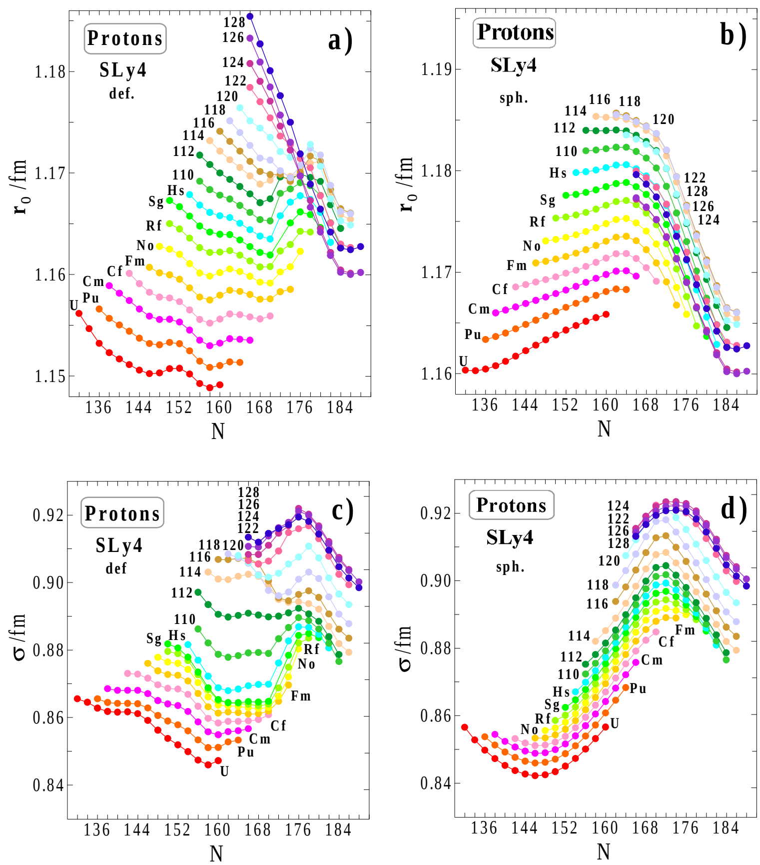

Fig. 1. Proton Helm parameters R_0 and σ parameters obtained for spherical and axially deformed shapes.

parameters ($r_0 = R_0/A^{1/3}$) calculated under the constraint of a spherical shape are systematically greater. However, as will be discussed in the forthcoming publication, this conclusion does not hold for the r.m.s. radii. In Fig. 2(c) one observes three minima in σ at $N = 152$, 162, and 184. Following the reasoning given in Ref. [7], one can conclude that these minima are related to the large energy gaps obtained for these neutron numbers [4].

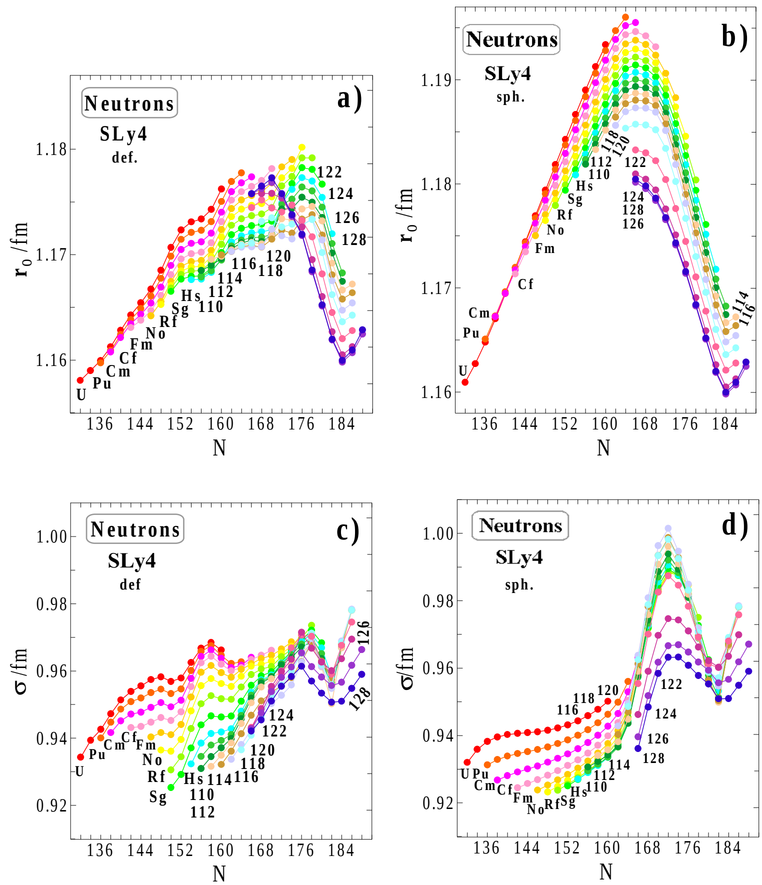

Fig. 2. Neutron Helm parameters R_0 and σ parameters obtained for spherical and axially deformed shapes.

For the protons (Fig. 1(c)), the energy gap occurs for $Z = 108$ [4] but the σ parameters are very close for $Z = 104,\ 106,\ 108$. The surface thickness increases for $Z = 110,\ 112,\ 114$, *i.e.*, when nucleons occupy orbits lying above the energy gap $Z = 108$.

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REFERENCES

[1] H. de Vries, C.W. Jager, C. de Vries, *At. Data Nucl. Data Tables* **36**, 495 (1987).

[2] E.G. Nadjakov, K.P. Marinova, *At. Data Nucl. Data Tables* **56**, 133 (1994).

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

[4] S. Ćwiok *et al.*, *Nucl. Phys.* **A611**, 211 (1996).

[5] S. Ćwiok, W. Nazarewicz, P.-H. Heenen, *Phys. Rev. Lett.* **83**, 1108 (1999).

[6] R.H. Helm, *Phys. Rev.* **104**, 1466 (1956).

[7] S. Mizutori *et al.*, *Phys. Rev.* **C61**, 044326 (2000).

[8] W. Nazarewicz, G. Rohoziński, G. Lalazissis, to be published.