Doubly magic properties in superheavy nuclei*

HUANG Ya-Wei(黄亚伟)[1;1)] ZHU Jian-Yu(朱剑钰)[2]

1 (Department of Mathematics and Physics, Wenshan Teacher's College, Wenshan 663000, Yunnan, China)
2 (School of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China)

Abstract A systematic study of global properties of superheavy nuclei in the framework of the Liquid Drop Model and the Strutinsky shell correction method is performed. The evolution equilibrium deformations, TRS graphs and α-decay energies are calculated using the TRS model. The analysis covers a wide range of even-even superheavy nuclei from $Z=102$ to 122. Magic numbers and their observable influence occurring in this region have been investigated. Shell closures appear at proton number $Z=114$ and at neutron number $N=184$.

Key words superheavy nucleus, magic property, TRS model, quadrupole deformation β_2, α-decay energy

PACS 21.10.Dr, 21.60.-n, 21.60.Cs, 23.60.+e, 27.90.+6

1 Introduction

The theoretical investigation of the superheavy nuclei region has been very intense in recent years. In order to search for the next doubly magic nucleus and island of stability located around it, many approaches have been applied to the area. Some predictions existed with significant discrepancy. Shell model calculations have been shown that the next spherical doubly magic nucleus after ^{208}Pb is the $^{310}126_{184}$, but many predictions were not completely identical, and some even opposite. Self-consistent calculations such as Skyrme-Hartree-Fock(SHF) using the interaction SkI4, SkM*, SkP[1, 2], and the recent drop Lublin-Strasbourg (LSD) model[3, 4], showed that the $N = 184$ is indeed a neutron magic number. But most of the relativistic mean field (RMF) model[2, 5] (including the axisymmetric RMF[6] and deformation RMF[7]) and SHF using SkI3 force[2] did not support that result (their predictions were $N=162$, 172, 174 and 198). There was a greater controversy in the next proton magic number after $Z=82$, different theoretical models predicted different results. Some calculations by SHF using SkM*, SkP force and macroscopic-microscopic model[2, 8] predicted that $Z=126$ has the magic structure, however some other predictions were $Z = 106$, 108, 110, 112, 114, 116, 120, 138. Among those predictions $Z=114$ was supported by most calculations, such as the SHF using SkI4[1, 2], the RHB using Gogny force[9], the RMF using TMAL[2] and RMF of axial symmetry[7], the MM model[3] et al. But other results of SHF using SkI3[1, 2], HFB using Sly4[3] and RMF using NL-Z2, LP-40 showed that this proton number did not have the shell effect. The macroscopic-microscopic model calculation predicted that the deformation double-magic nucleus and the spherical double-magic nucleus are ^{270}Hs and ^{298}114 respectively[10—13], the former has been discovered experimentally. The result described that the stability of nuclei near ^{270}Hs was enhanced[14], due to deformed shell structure of the nucleus.

In this paper the ground states of superheavy nuclear are investigated by TRS model. The shapes and α-decay energies are also predicted by the calculations. Our results are that the nucleus ^{298}114 is possibly the best candidates of spherical double-magic superheavy nuclei.

2 The model[15]

TRS calculation has appeared as a powerful tool to study the shapes and collective properties of nuclei. We will introduce it to superheavy nuclear research.

Received 3 September 2008

* Supported by National Natural Science Foundation of China (10735010,10525520) and Chinese Major State Basic Research Development Program (2007CB815000)

1) E-mail: hyw0926@sina.com

The TRS method[16] is a macroscopic-microscopic model approach in a uniformly rotating body-fixed frame of reference[17, 18]. The total Routhian of a nucleus is calculated on a grid in deformation space, using the Strutinsky shell correction method[19, 20]. The model employs the deformed Woods-Saxon potential of Ref. [21] and liquid-drop model of Ref. [22]. The pairing energy is calculated using a separable interaction of seniority and doubly stretched quadrupole type

$$\bar{\nu}^{(\lambda\mu)}_{\alpha\beta\gamma\delta} = -G_{\lambda\mu} g^{(\lambda\mu)}_{\alpha\bar{\beta}} g^{*(\lambda\mu)}_{\gamma\bar{\delta}} \quad (1)$$

where

$$g^{(\lambda\mu)}_{\alpha\bar{\beta}} = \begin{cases} \delta_\alpha \bar{\beta}, & \lambda=0, \mu=0, \\ \langle \alpha | \hat{Q}''_\mu | \bar{\beta} \rangle, & \lambda=2, \mu=0,1,2. \end{cases} \quad (2)$$

The above expression employs a good signature basis[23], $\bar{\alpha} = \hat{T}\alpha$ stands for the time-reversed state and $\overline{|r=\pm \mathrm{i}\rangle} = \pm |r = \mp \mathrm{i}\rangle$. To avoid the sudden collapse of pairing correlations, we use the Lipkin-Nogami approximate number projection[24].

The resulting cranked-Lipkin-Nogami (CLN) equation takes the form of the well known HFB-like equation. In the TRS model, the CLN equation is solved self-consistently at each frequency and each grid point in deformation space which includes quadrupole β_2, γ and hexadecapole β_4 shapes (pairing self-consistency). Finally, the equilibrium deformations are calculated by minimizing the total Routhian with respect to the shape parameters (shape self-consistency).

3 Results and discussion

We have calculated the TRS graph, quadrupole deformation including triaxiality deformation and α-decay energies Q_α in superheavy nuclei for Z= 102—120, N= 160—188. Fig. 1 shows results of quadrupole $\beta_2 \sim f(Z,N)$. On the one hand, β_2 remains the smallest for $Z = 114$ throughout the N region. On the other hand, β_2 has the minimum (≈ 0) at $N = 184$ and 186 for all Z, which is very similar to the situation around ^{208}Pb, in Fig. 2. The TRS model results

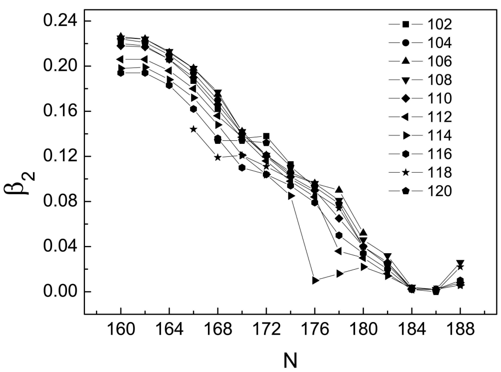

Fig. 1. Quadrupole deformation β_2 changes with Z, N in superheavy nuclei region.

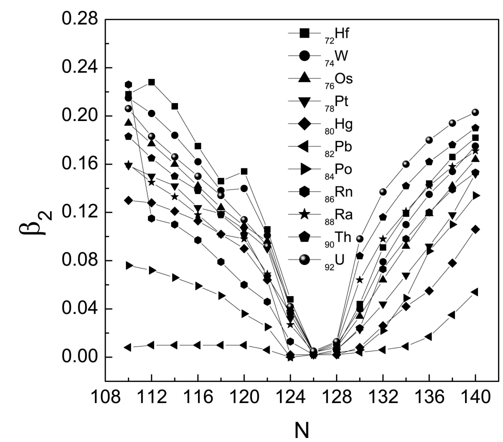

Fig. 2. Compared with the Pb and 114 isotopes, β_2 changes with Z, N.

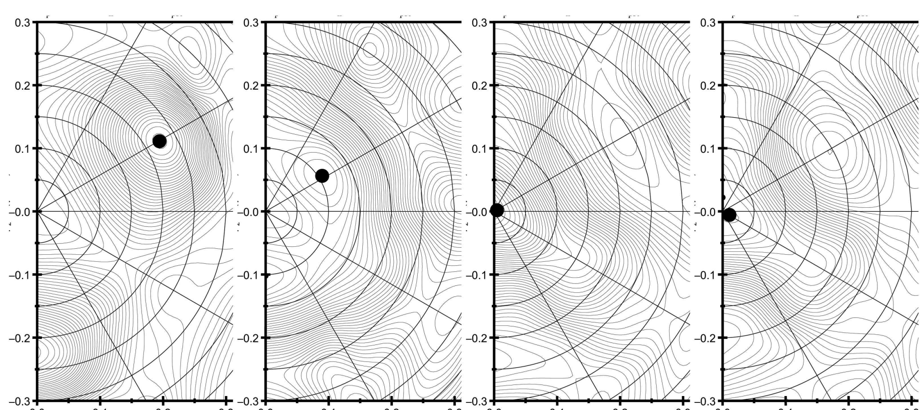

Fig. 3. TRS calculations for ^{268}106, ^{284}110, ^{298}114 and ^{306}118. The black dots represent the overall minimum in each panel, and the contours at 200 keV intervals.

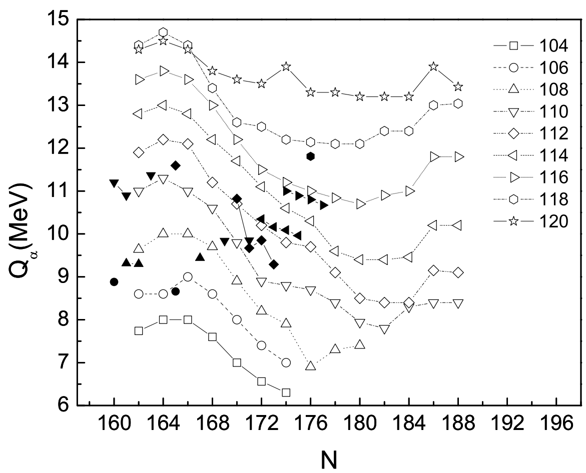

Fig. 4. α-decay energy Q_α changes with Z,N in superheavy nuclei. Experimental values are indicated by the full dots[25].

display the shape transitions are mainly from prolate to oblate, then again from the oblate to prolate. For example, for $Z = 114$ isotope chain, when N <184, along with N increasing, shapes of the nuclei display from a prolate to oblate, spherical shape transformations. But when N >186, they are again from spherical to oblate, prolate shape transformations. For the isotones, $N = 184$ and 186 are the obvious shape transition point. Significant triaxiality is not discovered in this region. Fig. 3 shows results of TRS calculations for ^{268}106, ^{284}110, ^{298}114 and ^{306}118. In the superheavy nuclear region, only even-even nucleus ^{184}114 has spherical shape in ground state, and the characters of strong spherical shell closure. Finally Fig.4 shows that between $N = 184$ and 186, α-decay energy Q has a big jump, which explains the character of $N = 184$ magic structure. The experimental data is also drawn in Fig.4 as comparisons. Our calculations agree with the experimental data.

In our investigation of the superheavy nuclei, the TRS graphs show nuclei heavier than ^{308}120 have super deformation of $0.439 \leqslant \beta_2 \leqslant 0.553$. The superdeformed states are possibly unstable.

4 Conclusions

We have presented results of constrained self-consistent calculations of superheavy nuclei by TRS method. The most obvious characteristics of the proton closed shell for $Z = 114$ in superheavy nuclei have been obtained. For neutron number, the main shell closure locates at $N = 184$ or 186. The magic number is confirmed as $N = 184$, by the analysis of α-decay energies Q_α. From these calculations, it could be concluded that ^{184}114 is likely to be the only double-magic spherical nucleus in superheavy nuclei region.

References

1 Bürvenich T, Rutz K, Bender M et al. Eur. Phys. J. A, 1998, **3**: 139
2 Rutz K, Bender M, Bürvenich T et al. Phys. Rev. C, 1997, **56**: 238
3 Baran A, Łojewski Z, Sieja K. Eur. Phys. J. A, 2005, **25**: 611
4 Baran A, Łojewski Z, Sieja K. Acta Phys. Pol. B, 2005, **36**: 1369
5 Baran A, Łojewski Z, Sieja K et al. Phys. Rev. C, 2005, **72**: 044310
6 Patra S K, WU C L, Praharaj C R et al. Nucl. Phys. A, 1999, **651**: 117
7 REN Z Z. Phys. Rev. C, 2002, **65**: 051304
8 Ćwiok S, Nazarewicz W, Heenen P H. Phys. Rev. Lett., 1999, **83**: 1108
9 Sharma M, Lalazissis G, König J, Ring P. Phys. Rev. Lett., 1995, **74**: 3744
10 Oganessian Y T et al. Phys. Rev. C, 2004, **69**: 021601
11 Myers W D, Swiatecki W J. Nucl. Phys. A, 1996, **81**: 1
12 Sobiczewski A, Gareev F A, Kalinkin B N. Phys. Lett., 1966, **22**: 500
13 Nilsson S G, Tsang C F, Sobiczewski A et al. Nucl. Phys. A, 1969, **131**: 1
14 Moody K et al. Nucl. Phys. A, 2004, **734**: 188
15 XU F R, Satuła W, Wyss R. Nucl. Phys. A, 2000, **669**: 119
16 Nazarewicz W, WyssR, JohnsonA. Nucl. Phys. A, 1989, **503**: 285
17 Inglis D R. Phys. Rev., 1954, **96**: 1059
18 Inglis D R. Phys. Rev., 1955, **97**: 701
19 Strutinsky V M. Yad. Fiz., 1966, **3**: 614
20 Strutinsky V M. Nucl. Phys. A, 1967, **95**: 420
21 Ćwiok S, Dudek J, Nazarewicz W et al. Comp. Phys. Comm., 1987, **46**: 379
22 Cohen S, Plasil F, Swiatecki W J. Ann. Phys., 1974, **NY82**: 557
23 Goodman A L. Nucl. Phys. A, 1974, **230**: 466
24 Pradhan H C, Nogami Y, Law J. Nucl. Phys. A, 1973, **201**: 357
25 Nuclear Data Sheets, 2005, **106**: 251—366