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Structure of superheavy nuclei

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A short review of the results on the structure of superheavy nuclei is presented.

Keywords: superheavy, nuclear mean field, alpha-decay.

Introduction

Superheavy nuclei form a new region of the nuclide chart whose structure is only started to be investigated. It is interesting if their structure is similar to that of nuclei which have been already studied or unexpected features will be discovered. The specific feature of atomic nuclei is a self consistent mean field whose characteristics determine a shape of atomic nucleus, its excitation spectra and decay modes. The following theoretical approaches are used to determine the properties of self consistent mean field: the microscopic-macroscopic method and the self consistent mean field models (relativistic or non-relativistic) based on nuclear energy density functional. Both approaches are phenomenological, however, in the second one the nuclear mean field is consistently determined with a good description of the global nuclear properties.

Shell effects

We use in our calculations the two-center shell model potential (TCSM) which is useful for the description of nuclear structure and reactions [1]. The parameters of the nuclear average mean field potential were set to describe the spins and parities of known rare earth, actinides and superheavy nuclei [2]. Weak dependence on (N-Z) was incorporated in the momentum dependent part of the single particle Hamiltonian. The ground state spins of nuclei with N=147-161 are presented in Tables I and II. One can see a good description up to Sg isotopes.

Table 1.
Calculated and experimental ground state spins of the indicated nuclei with N=147-161. The tentative assignments of spins are in brackets.

N	Cm	Cf	Fm Exp	Cal Exp	Cal Exp	Cal
147	$5/2^+$	$5/2^+$	$(1/2^+)$	$5/2^+$		
149	$7/2^+$	$7/2^+$	$(7/2^+)$	$7/2^+$	$(7/2^+)$	$7/2^+$
151	$9/2^-$	$9/2^-$	$9/2^-$	$9/2^-$	$(9/2^-)$	$9/2^-$
153	$1/2^+$	$1/2^+$	$1/2^+$	$1/2^+$	$1/2^+$	$1/2^+$
155	$(1/2^+)$	$1/2^+$	$(7/2^+)$	$7/2^+$	$7/2^+$	$7/2^+$
157			$(7/2^+)$	$7/2^+$	$(9/2^+)$	$9/2^+$

Table 2.
Calculated and experimental ground state spins of the indicated nuclei with N=147-161. The tentative assignments of spins are in brackets.

N	No Exp	Cal	Rf Exp	Cal	Sg Exp	Cal
149	$(7/2^+)$	$7/2^+$				
151	$(9/2^-)$	$9/2^-$	$(9/2^-)$	$9/2^-$		
153	$(1/2^+)$	$1/2^+$	$(1/2^+)$	$1/2^+$	$(1/2^+)$	$1/2^+$
155	$(3/2^+)$	$1/2^+$		$1/2^+$		$1/2^+$
157	$(9/2^+)$	$9/2^+$		$11/2^-$		$9/2^-$
159					$(9/2^+)$	$9/2^+$

The structure of superheavy nuclei crucially influences the evaporation residue cross sections in actinide-based reactions. The results of calculations of (B_f -B_n) provides the shell at Z=114. However, the shell effects at Z=120-126 are rather strong. Since for nuclei with Z=120-126 the Q_α is minimal at Z=120 where the fission barrier is rather high, the nuclei with Z=120, N=180-184 are expected to be the most stable beyond those with Z=114, N=176-178.

The information on the proton magic number after Z=82 is contained also in the spectra of the proton two-quasiparticle states. While for nuclei with $Z \leq 118$ the calculated energies of the first proton two-quasiparticle states are smaller than 1.2 MeV, in $^{296;298}120$ the calculated energies of the first proton two-quasiparticle states are above 1.9 MeV (Figure 1) [3]. This indicates a large gap in the proton single-particle spectrum.

The measurements of the α -decay spectra of superheavy nuclei can give us an information on the isomers. Around ^{250}Fm one can find both protons and neutrons

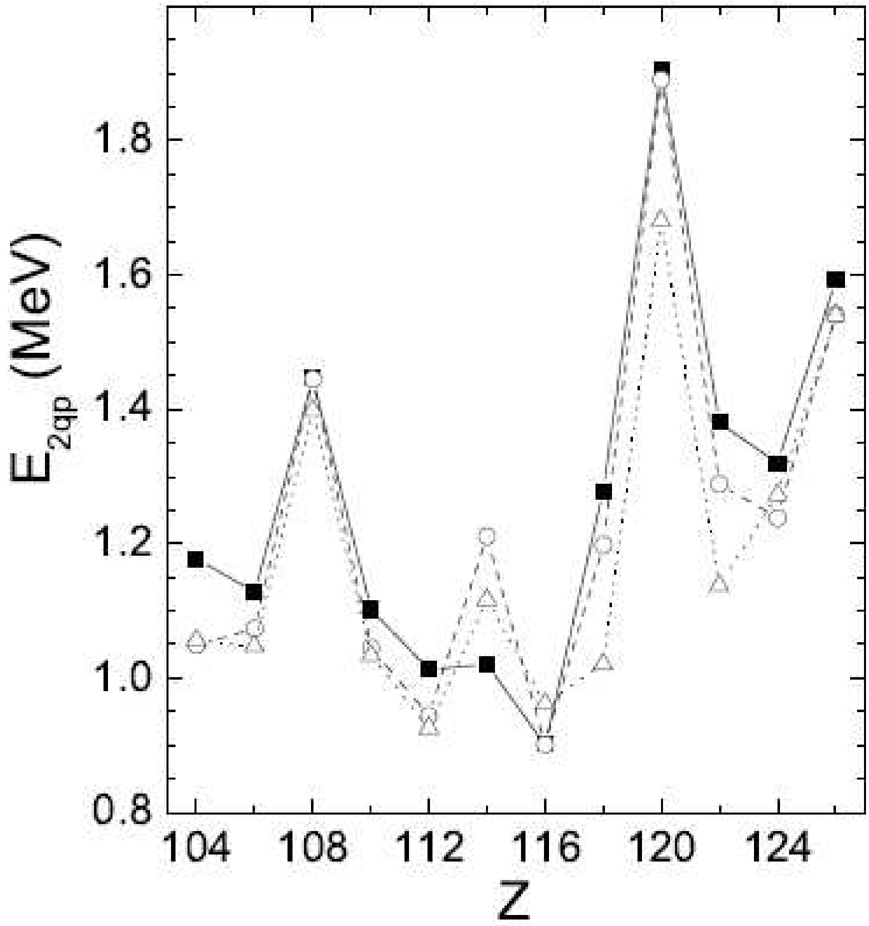

Figure 1. Energies of the two-quasiparticle proton states in alpha-decay chains containing $^{296,298,300}120$ nuclei.

pairs of levels close to the Fermi level that can be coupled to low-lying states with high K, such as $(9/2^-[734] \times 7/2^+[624])_n 8^-$ for neutrons, or $(9/2^+[624] \times 7/2^-[514])_p 8^-$ and $(7/2^-[514] \times 7/2^+[633])_p 8^-$ for proton pairs. The lowest calculated states in the N=155 isotonic chain have $\Delta K \geq 3$. Therefore, the long-living isomeric state is expected in N=155 isotones (Figure 2) [4]. If the energy of this isomer is small, its lifetime is long enough and the α-decay could occur from this isomer. The calculated ground state spin changes in ^{257}No when the value of β_4 decreases. Therefore, a small change of deformation could cause the inversion of the levels $1/2^+$ and $7/2^+$ which are close in energy in dense spectrum.

The lowest calculated states in ^{263}Sg and ^{265}Hs have $\Delta K \geq 4$. So, the first excited states in ^{263}Sg and ^{265}Hs can be related to the observed states at 130 keV and above 300 keV, respectively. The lowest $3/2^+$ state can be isomeric in ^{257}Fm, ^{259}No, and ^{261}Rf (Figure 3) [4] .

α-decay

In ^{285}Fl the single-particle state 9/2 [604] could be the isomeric one from which α-decay can occur with $T_\alpha \approx 3$ ms. The α-decay of ^{277}Ds can occur from the isomeric 9/2 [604] and ground state 3/2 [611]. The ground 3/2 [611] and isomeric

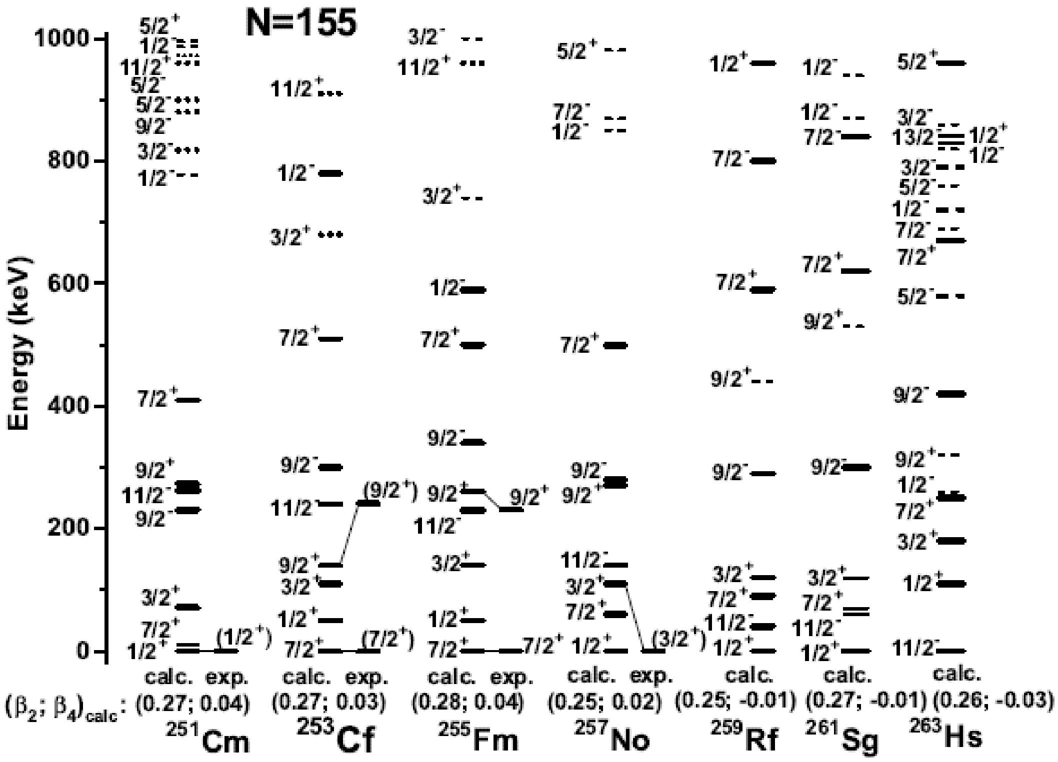

Figure 2. The lowest calculated states in the N=155 isotonic chain.

13/2 [716] states of ^{273}Hs are populated in the α-decay chain of ^{285}Fl. The α-decay from these states populates the corresponding states in ^{269}Sg from which the α-decays with $T_{\alpha} \geq 410$ s occur and compete with spontaneous fission. In ^{293}Lv the 7/2[604] state is close in energy to the ground state.

The Skyrme-Hartree-Fock calculations indicate possibility of the two close lines in α-decay spectrum of ^{293}Lv [5]. After the γ-transitions the α-decay of ^{289}Fl likely occurs from the ground state. So, in the α-decay chain of ^{293}Lv there are single lines in the α-decay spectra of ^{289}Fl, ^{285}Cn, ^{281}Ds, and ^{277}Hs. The isomeric states 15/2 [707] (^{289}Fl, ^{285}Cn), 11/2 [606] (^{281}Ds) and 9/2 [604] (^{277}Hs) do not affect the α-decay chain and can be explored in the direct production of these nuclei.

Phase transition

Phase transition phenomenon, especially, shape phase transition is a very interesting subject of investigations which became widespread in nuclei removed out of the valley of stability. It is interesting to look for the possible manifestation of this phenomenon in superheavy nuclei. There are several known indicators of the phase transitions. One of them is a level density parameter. In Figure 4 the calculated proton a_Z and neutron a_N level density parameters are shown for superheavy nuclei belonging to the α-decay chains containing ^{296,298,300}120 isotopes, calculated using two-center shell model [6].

As seen, a_Z has a minimum at Z=120 and a_N has a minimum at N=184. This

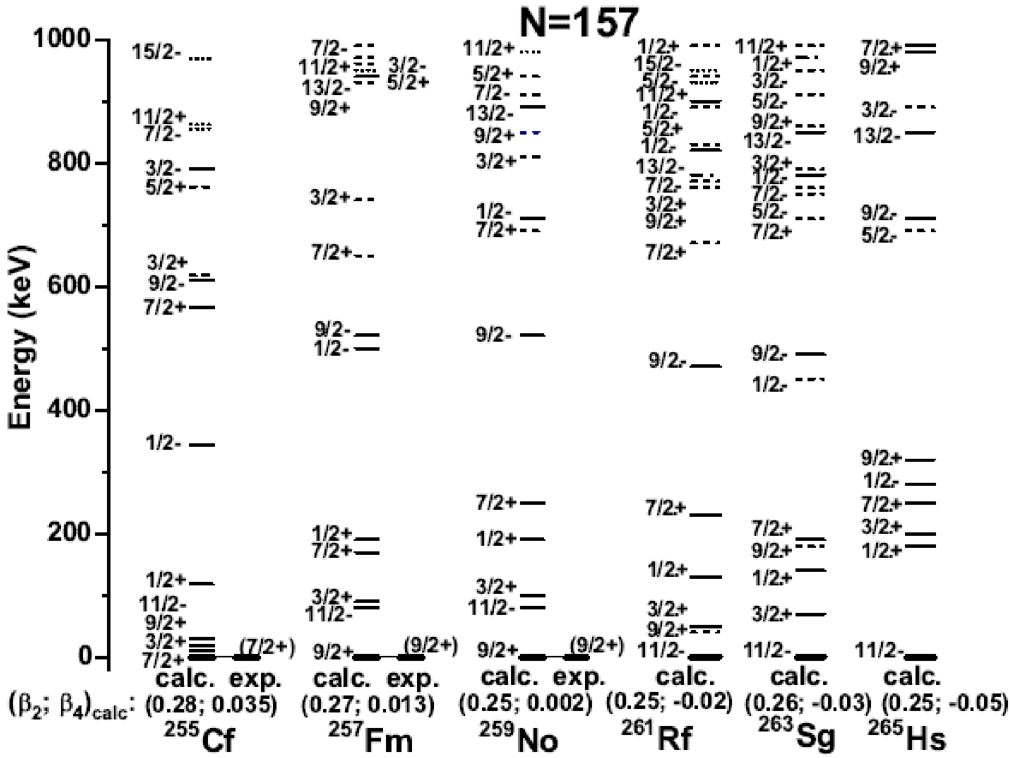

Figure 3. The lowest calculated states in the N=157 isotonic chain.

indicates Z=120 and N=184 as a possible proton and neutron magic numbers, respectively. The proton level density parameter has a maximum at Z=112 indicating Z=112 as a transition point from deformed to spherical nuclei.

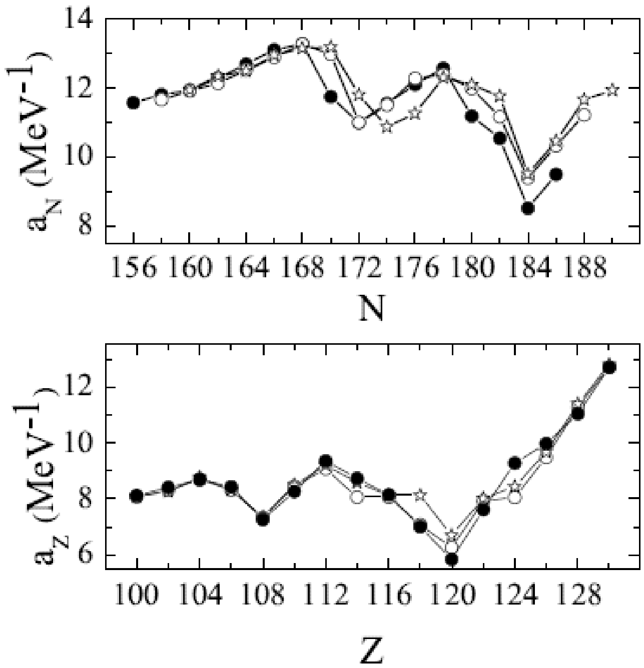

Figure 4. Calculated neutron (a_N) and proton (a_Z) level density parameters as a function of neutron number N (upper part) and proton number Z (lower part). The nuclei from alpha-decay chains containing $^{296}120$, $^{298}120$, $^{300}120$ are marked by closed circles, open circles, and stars, respectively.

References

[1] J. Maruhn, W. Greiner, Z. Phys. A **251** (1972) 431.
[2] A.N. Kuzmina et al., Phys. Rev. C **85** (2012) 014319.
[3] A.N. Kuzmina et al., Eur. Phys. J. A **47** (2011) 145.
[4] G.G. Adamian et al., Phys. Rev. C **97** (2018) 034308.
[5] V.G. Kartavenko et al., Chin. Phys. C **41** (2017) 074105.
[6] A.N. Bezbakh et al., Eur. Phys. J. A **50** (2014) 97.