STABILITY OF SUPERHEAVY ELEMENTS IN SKYRME HFB APPROACH*

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Half-lives of superheavy elements (SH) with $108 \leq Z \leq 126$ and $148 \leq N \leq 188$ are calculated from decay energies, fission barriers and the mass parameters that have been obtained in a uniform microscopic way within a selfconsistent Hartree–Fock–Bogoliubov (HFB) method, SkM* force in the particle–hole channel and the density dependent delta interaction in the particle–particle channel. We consider α-decay, spontaneous fission (SF) and β processes ($\beta^{\pm}$ and electron capture). The results indicate that the longest total half-lives are of the order of seconds for a set of nuclei in the vicinity of $Z = 112$, $N = 182$.

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1. Introduction

The SH elements are unstable with respect to elementary nuclear processes such as α-decay, spontaneous fission (SF) and all types of β radiation ($\beta^{\pm}$ decay and electron capture — EC). The calculations done to date mainly in a framework of macroscopic–microscopic models show a possible stability region spreading around the $Z = 110$ and $N = 184$ nucleus and the total half-life predicted is about $10^{9.4}$ years [1, 2]. The estimates of the α- and β-decay half-lives were presented in Ref. [3], where the selfconsistent Hartree–Fock + BCS model was used.

Considering fission process, the important issue is the inclusion of non-axial and left–right asymmetric shapes of the fissioning systems. In the presented paper, such shapes were taken into account in a selfconsistent way. The HFB + BCS calculations of spontaneous fission half-lives have been reported recently in [4]. However, the axial asymmetry which is crucial for the estimation of the fission half-lives was not taken into account. The effects

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due to breaking of axial symmetry are known to be important around the first saddle point and around the second barrier. The reflection-asymmetric mode contributes at large elongations, beyond the first fission barrier.

In the following, the full HFB calculations with SkM* force in the particle–hole channel are reported. Results shown in the present paper are obtained taking into account possible asymmetries of the nuclear shapes, namely the left–right asymmetry and nonaxiality.

The details of our calculations concerning spontaneous fission process are described in [5]. The corresponding cranking approximation to the adiabatic time dependent HFB (ATDHFB) theory of collective inertia used in the calculations of the spontaneous fission half-lives has been presented in [6].

Since our HFB calculations are limited to the even–even nuclei, estimations of β-decay Q-values were performed in a quasi-particle approximation for the masses of the odd–odd daughter nuclei [3]. The half-lives against β-decay were determined from Q-values in the same approximation as in Ref. [1]. The α-decay half-lives were calculated according to Viola–Seaborg formula with the parameters given in Ref. [7].

2. Results

Since the spontaneous fission and α-decay half-lives have been already presented [5], in the following, we discuss only the β-decay properties and the total half-lives of even–even SH nuclei.

The results of the β-decay half-lives are shown in Fig. 1. The half-lives in the β-channel are of the order of 0.1–10 seconds in the considered region of SH nuclei. The beta stability valley stretches around the line passing through the points $(N, Z) = (178, 108)$ and $(188, 116)$.

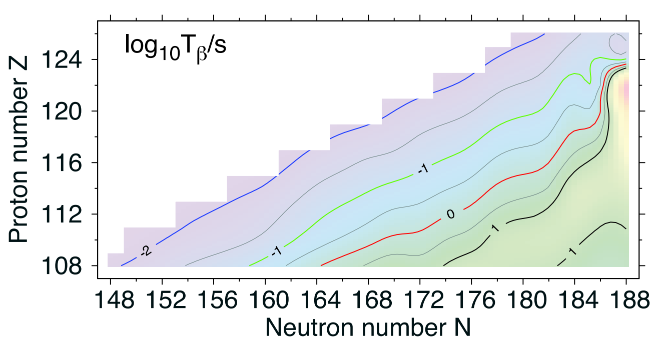

Fig. 1. (Color online) Decimal logarithms of β-decay half-lives (seconds).

Figure 2 shows the total half-lives including all considered modes of decay: α, β and SF. The longest total half-lives correspond to nuclei in the vicinity of $Z = 112$ and $N = 182$–184 and their values are of the order of seconds. The dominant processes in the considered region are both the α-decay and the spontaneous fission.

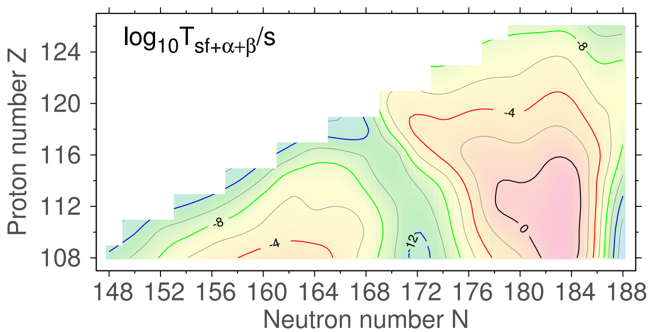

Fig. 2. (Color online) Decimal logarithms of total half-lives SF+α+β (seconds).

TABLE I

Experimental data [8–10] for α-decay energies Q_α (MeV) and total half-lives T *versus* theoretical results T_α, $T_{\rm SF}$ and T_β (in seconds).

Nucleus	(Ref.)	Experiment				Theory			
^{A}Z	—	Q_α	T	$\log T$	Mode	$Q_\alpha^{\rm th}$	$\log T_\alpha$	$\log T_{\rm SF}$	$\log T_\beta$
^{264}Hs	[8]	—	0.45 ms	−3.35	α/SF	11.41	−5.13	−3.64	−4.73
	[9]	—	0.26 ms						
^{266}Hs	[8–10]	—	2.3 ms	−2.64	α	10.93	−3.64	−2.45	−3.72
^{270}Hs	[8]	9.08	10 s	1.00	α	10.31	−2.52	0.01	−1.65
	[9]	—	30 s						
	[10]	9.30	3.6 s						
^{270}Ds	[8]	—	0.1 ms	−4.00	α	11.96	−5.77	−3.10	−4.55
	[9]	—	100 μs / 6 ms						
	[10]	11.20	0.10 ms						
^{282}Cn	[8]	—	0.8 ms	−3.10	SF	11.74	−4.72	−8.03	−9.61
	[9]	—	73 ms						
	[10]	$<$ 10.82	0.50 ms						
^{284}Cn	[8, 9]	—	97 ms	−1.01	SF	10.99	−2.99	−9.15	−10.83
	[10]	$<$ 9.85	101 ms						
^{286}Fl	[8, 9]	10.19	0.13 s	−0.89	α/SF	11.43	−3.45	−7.53	−9.59
	[10]	10.345	0.16 s						
^{288}Fl	[8–10]	9.94	0.8 s	−0.10	α	10.64	−1.49	−5.06	−6.97
^{290}Lv	[8]	11.84	7 ms	−2.15	α	11.35	−2.69	−1.88	−3.47
	[9]	—	7.1 ms						
	[10]	11.00	15 ms						
^{292}Lv	[8–10]	10.66	18 ms	−1.74	α	10.94	−1.67	0.96	−0.54
^{294}118	[8, 9]	11.65	0.9 ms	−3.05	α	11.80	−3.18	2.91	1.75
	[10]	11.81	1.8 ms						

Table I summarizes the existing experimental data and shows the results predicted in our calculations. The experimental decay modes are displayed in column five. The agreement is rather good for the decay modes with an exception of ^{288}Fl, for which, contrary to the experimental data, the spontaneous fission is calculated to be the main decay channel.

The discrepancies between the theoretical and experimental data are rather large in the region of the middle mass SH nuclei. Since those systems belong to the region of shape coexistence, some further increase of SF half-lives is anticipated due to the shape mixing. Other improvements of the current model include dynamical treatment of penetrability by considering several collective coordinates, improved energy density functionals [11], and the full ATDHFB inertia. Work along these lines is in progress.

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