Alpha decay energies and half-lives for possibly synthesized superheavy elements*

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Abstract We investigate the ground state properties of some superheavy nuclei, which may be synthesized in future experiments. Special emphases are placed on the alpha decay energies and half-lives. The alpha decay energies and half-lives from different theoretical models are compared and discussed comprehensively. Through these calculations and comparisons, the optimal superheavy elements to be synthesized in future experiments are proposed theoretically.

Key words synthesis, superheavy element, alpha decay energy, half-life

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1 Introduction

The synthesis of new element is always an interesting topic in nuclear physics. In 1995—1996, the superheavy elements Z=110, 111 and 112 were successfully synthesized at GSI laboratory in Germany[1—3]. Since then, the synthesis of superheavy elements has been speeded up greatly. Many new superheavy elements and isotopes were successfully produced in past years[4—13], owing to the rapid development of modern accelerators and detectors. The elements Z=114 and 116 were produced at Dubna via hot-fusion reactions by Oganessian et al.[4, 5] in 1999—2001. The element Z=110 was confirmed by Lawrence Berkeley National Laboratory in USA[9]. At RIKEN in Japan, Morita et al. repeated the experiments on the production of Z=110 and Z=111 that were performed at GSI in Germany during 1994—1996[10]. Their experiments confirmed the synthesis of Z=110 and Z=111 at GSI. After the confirmation of Z=110 and Z=111, Morita et al. reported that they have synthesized one event of new element Z=113 through the cold-fusion reaction[11]. The element Z=111 was reported also by Lawrence Berkeley National Laboratory[12]. In 2005, new superheavy isotopes of Z=113 and Z=115 were reported at Dubna by Yu. Ts. Oganessian et al[7]. Very recently, the Dubna group reported that the element with atomic number Z=118 was synthesized in the ^{294}Cf+^{48}Ca reaction[8]. The rapid progress in synthesis of new elements has promoted the experimental and theoretical studies on superheavy nuclei.

At the Institute of Modern Physics in Lanzhou, GAN et al. synthesized new isotope ^{259}Db[13] in 2000. In 2004 they produced the new isotope ^{265}Bh[14, 15]. After the successful production of these new isotopes, Chinese physicists are aiming at the synthesis of new superheavy elements. In 2004, Ren and Gan proposed to produce the new isotope of Z=110 by the ^{40}Ar+^{238}U reaction[16]. In 2006, Gan et al carried out an experiment at Lanzhou in order to produce $^{274-276}$Ds (Z=110) by this reaction. In the process of searching new superheavy elements, theoretical calculations are useful for the design of experiments to synthesize new superheavy elements. In this paper, we will calculate the ground state properties of some superheavy nuclei, which are the good candidates for future experiment at Lanzhou. Special emphases are placed on the calculations of alpha-decay energies and

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half-lives. The alpha-decay energies and half-lives from different models are compared and some predictions are made.

This paper is organized in the following way. The theoretical results and detailed discussions are given in Section 2. The last Section is a short summary.

2 Numerical results and discussions

There are some theoretical studies of superheavy nuclei by using different models[17—24]. In this paper, we use the macroscopic-microscopic (MM) model with the Nilsson potential to calculate the ground state properties of superheavy nuclei. The Nilsson parameters used are the standard parameters[21, 23]. BCS method is used to calculate the pairing energy. Axial deformation of superheavy nuclei is assumed in this calculation. Details of MM model calculation can be seen in Refs. [21—24]. The numerical results will be discussed in the following.

In Table 1 and Table 2, we list the calculated α-decay energies and half-lives for the superheavy elements, which may be synthesized in future experiments. In Tables 1—2, the first column is the nuclear reaction used to produce new superheavy isotopes. The second column is the possible product of the reaction (the maximum number of neutron evaporation is assumed to be 4). The 3—4 columns are the calculated alpha-decay energies and the half-lives. The calculated results from Möller's calculation[24] are listed in columns 5—6 for comparison. The experimental data, taken from the NUBASE table[25], are listed in the last two columns. The half-lives are obtained by the Viola-Seaborg formula with new parameters[26].

In Table 1, one can see that the calculated α-decay energies agree well with the experimental data. The maximum difference between the calculated results and the experimental data is within 0.5 MeV. As a theoretical model, this agreement is rather good. Compared with Möller's calculation, one can see that, our calculation is also close to the results of Möller's calculation. However, one can see in Table 1 that our results are slightly closer to the estimated values from the NUBASE table[25]. As to the half-lives, one can see that the calculated results are also close to the experimental data and to the results from Möller's calculation. The ratios between the calculated half-lives and the experimental values are approximately within 10 times. Generally speaking, the half-lives of most nuclei in Table 1 are in the order of milliseconds. Both MM model calculations and the estimated values[25] show that the half-lives of $^{280}110$ and $^{279}110$ are in the order of seconds. Accordingly, these nuclei might be easily detected in the experimental process, thereby they will be the suitable choices for the future experiments.

Table 1. The α-decay energies and half-lives of superheavy isotopes.

reaction	nuclei	MM model		Möller		Exp.	
		Q_α	T/ms	Q_α	T/ms	Q_α	T/ms
$^{36}S+^{238}U$	$^{274}108$	9.51	6.258×10^2	9.46	8.725×10^2	9.50#	6.687×10^2#
	$^{273}108$	9.60	2.711×10^3	9.42	8.928×10^3	9.90#	4.001×10^2#
	$^{272}108$	9.70	1.812×10^2	9.20	5.130×10^3	10.10#	1.497×10#
	$^{271}108$	10.01	2.027×10^2	8.82	6.151×10^5	9.90#	4.001×10^2#
	$^{270}108$	9.66	2.345×10^2	8.69	2.082×10^5	9.30	2.573×10^3
$^{37}Cl+^{238}U$	$^{275}109$	10.05	1.593×10^2	10.06	1.498×10^2	10.48	1.227×10
	$^{274}109$	10.33	6.842×10	10.06	3.479×10^2	10.50#	2.538×10#
	$^{273}109$	10.39	2.070×10	9.82	6.723×10^2	10.82#	1.802#
	$^{272}109$	10.70	8.149	9.43	2.022×10^4	10.60#	1.432×10#
	$^{271}109$	10.44	1.546×10	9.30	2.119×10^4	10.14#	9.189×10#
$^{40}Ar+^{238}U$	$^{278}110$	10.12	5.828×10	10.41	1.017×10	10.00#	1.227×10^2#
	$^{277}110$	10.35	1.136×10^2	10.69	1.580×10	10.30#	1.531×10^2#
	$^{276}110$	10.59	3.570	10.73	1.610	10.60#	3.371#
	$^{275}110$	10.71	1.411×10	10.73	1.260×10	11.10#	1.653 #
	$^{274}110$	10.87	7.375×10^{-1}	10.51	5.667	11.40#	4.377×10^{-2}#
$^{48}Ca+^{232}Th$	$^{280}110$	9.62	1.420×10^3	9.05	7.433×10^4	9.30#	1.252×10^4#
	$^{279}110$	9.85	2.483×10^3	9.68	7.479×10^3	9.60#	1.269×10^4#
	$^{278}110$	10.12	5.828×10	10.41	1.017×10	10.00#	1.227×10^2#
	$^{277}110$	10.35	1.136×10^2	10.69	1.580×10	10.30#	1.531×10^2#
	$^{276}110$	10.59	3.570	10.73	1.610	10.60#	3.371#

Note: The experimental data are taken from the NUBASE table[24]. # denotes the estimated values from Ref. [24].

Table 2. The α-decay energies and half-lives of superheavy isotopes.

reaction	nuclei	MM model		Möller		Exp.	
		Q_α	T/ms	Q_α	T/ms	Q_α	T/ms
^{41}K+^{238}U	^{279}111	10.41	7.827×10	10.92	4.192	10.52*	4.089×10
	^{278}111	10.64	4.732×10	11.39	7.822×10^{-1}	10.72#	2.993×10#
	^{277}111	10.75	1.087×10	11.50	1.909×10^{-1}	11.18#	1.019#
	^{276}111	10.90	1.088×10	11.52	4.002×10^{-1}	11.32#	1.127#
	^{275}111	11.10	1.566	11.32	4.854×10^{-1}	11.55#	1.479×10^{-1}#
^{45}Sc+^{238}U	^{283}113	10.25	8.874×10^2	9.35	3.512×10^5	10.26*	8.341×10^2
	^{282}113	10.16	3.616×10^3	9.78	4.225×10^4		
	^{281}113	11.46	8.927×10^{-1}	10.69	6.301×10		
	^{280}113	11.58	1.110	11.46	2.073		
	^{279}113	12.65	2.709×10^{-3}	12.62	3.104×10^{-3}		
^{55}Mn+^{238}U	^{293}117	11.47	1.226×10	11.68	3.975		
	^{292}117	11.47	2.847×10	11.70	8.308	11.60#	1.413×10#
	^{291}117	11.67	4.191	11.72	3.219	11.90#	1.262 #
	^{290}117	11.93	2.512	11.19	1.342×10^2		
	^{289}117	12.31	1.615×10^{-1}	11.98	8.378×10^{-1}		
^{59}Co+^{232}Th	^{291}117	11.67	4.191	11.72	3.219	11.90#	1.262 #
	^{290}117	11.93	2.512	11.19	1.342×10^2		
	^{289}117	12.31	1.615×10^{-1}	11.98	8.378×10^{-1}		
	^{298}117	12.63	8.084×10^{-2}	12.02	1.588		
	^{287}117	12.76	1.897×10^{-2}	12.09	4.803×10^{-1}		

Note: The experimental data are taken from the NUBASE table[24]. # denotes the estimated values from Ref. [24]. ∗ denotes the experimental results from Ref. [7].

Table 3. The calculated α-decay energies and half-lives of superheavy elements are compared with the results from RMF models.

nuclei	Q_α Cal.	Q_α TMA	Q_α NLZ2	Q_α Exp.	T/ms Cal.	T/ms TMA	T/ms NLZ2	T/ms Exp.
^{275}109	10.05	9.71	10.43	10.48*	1.59×10^2	1.36×10^3	1.64×10	1.23×10
^{274}109	10.33	9.74	10.97	10.5#	6.84×10	2.61×10^3	1.85	2.54×10#
^{273}109	10.39	9.79	10.89	10.82#	2.07×10	1.80	1.23	1.80#
^{272}109	10.70	9.89	10.4	10.6#	8.15	1.43×10	4.54×10	1.43×10#
^{271}109	10.44	9.99	10.1	10.14#	1.55×10	9.19×10	1.17×10^2	9.19×10#
^{279}111	10.41	10.45	9.96	10.52*	7.83×10	6.17×10	1.25×10^3	4.09×10
^{278}111	10.64	10.5	10.26	10.72#	4.73×10	1.07×10^2	4.48×10^2	2.99×10#
^{277}111	10.75	10.43	10.85	11.18#	1.08×10	6.95×10	6.19	1.02#
^{276}111	10.90	10.75	11.39	11.32#	1.10×10	2.52×10	7.82×10^{-1}	1.13#
^{275}111	11.10	10.89	11.62	11.55#	1.56	4.95	1.04×10^{-1}	1.48×10^{-1}#
^{283}113	10.25	11.28	9.76	10.26*	8.87×10^2	2.32	2.08×10^4	8.34×10^2
^{282}113	10.16	11.36	10.01		3.62×10^3	3.52	9.38×10^3	
^{281}113	11.46	11.28	10.33		8.92×10^{-1}	2.32	5.42×10^2	
^{280}113	11.58	11.2	10.76		1.11	8.31	9.75×10	
^{279}113	12.65	11.06	11.17		2.71×10^{-3}	7.71	4.21	
^{293}117	11.47	11.31	10.42		1.23×10	2.95×10	5.64×10^3	
^{292}117	11.47	11.00	10.58	11.6#	2.85×10	3.97×10^2	4.86×10^3	1.41×10#
^{291}117	11.67	10.64	11.22	11.9#	4.19	1.45×10^3	4.88×10	1.26#
^{290}117	11.93	10.57	11.52		2.51	5.16×10^3	2.17×10	
^{289}117	12.31	11.09	11.75		1.61×10^{-1}	1.02×10^2	2.75	
^{288}117	12.63	12.27	11.95		8.10×10^{-2}	4.56×10^{-1}	2.27	
^{287}117	12.76	13.25	12.15		1.90×10^{-2}	2.09×10^{-3}	3.56×10^{-1}	

Note: ∗ denotes the experimental results from Ref. [7].

In Table 2, one can see that the calculated α-decay energies agree well with the experimental data. For heavier superheavy nuclei listed in Table 2, one can see that the half-lives become shorter. The half-lives of most nuclei are about several milliseconds. In Table 2, one can see that the calculated results are also close to the results of Möller's calculation, except for ^{283}113. Recent experiment suggests that the experimental α-decay energy of ^{283}113 is 10.26 MeV[7], which is much closer to our results than to Möller's. Table 3 compares the MM results with our previous relativistic mean-field (RMF) model results[17—19].

One can see that the MM results are close to the results of RMF models. The MM model calculations and the RMF model calculations with NL-Z2 parameters show that the half-life of $^{282}113$ is about several seconds. This indicates that $^{282}113$ may be detected easily in future experiment. On the whole, the calculated results are close to the results from Möller's calculations, to the RMF model results and to the experimental data (including the estimated values).

In Table 2 and Table 3, one can see that both MM model calculations and the estimated values from the NUBASE table show that the half-lives of isotopes with Z=117 are in the order of milliseconds. This indicates that, to synthesis new superheavy isotopes with Z=117, one may need more advanced detector to detect these isotopes. However, in Table 3, unlike the MM model, the RMF model results show that the isotopes $^{289-293}117$ may have longer half-lives. This implies that these nuclei can be detected more easily than we have expected. This needs to be verified in future experiments.

3 Conclusions

In conclusion, with the MM model, we calculate the α-decay energies and half-lives of some superheavy nuclei which may be synthesized in future experiments at Lanzhou. The calculated results are compared with the results of Möller's calculation, with our previous RMF model results and with the experimental data (including the estimated values). The calculated results are consistent with the experimental data and with the results of Möller's calculation and with the RMF model results. The calculated α-decay energies and half-lives of unknown nuclei are useful for future experiments designed to synthesize new superheavy elements. Some superheavy nuclei are proposed to be the optimal candidates for future experiments.

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