



## Alpha decay half-lives of superheavy nuclei with $Z=100-120$

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### Abstract

We have investigated the alpha decays from even-even superheavy nuclei with  $Z=100-120$  within the framework of the shifted Deng-Fan potential model using the Wentzel-Kramers-Brillouin (WKB) method by considering the Bohr-Sommerfeld quantization condition. The calculated half-lives are compared with the experimental data and the recent theoretical values. The obtained results indicate that the shifted Deng-Fan potential is capable of describing alpha decays from superheavy nuclei.

**Keywords:** Deng-Fan potential, WKB method, Alpha decay, Superheavy nuclei

### Introduction

The alpha decay of superheavy nuclei is taken into consideration by many nuclear researchers in recent years and it is the monopolized way to identify new superheavy nuclei. Theoretical models to investigate the cluster radioactivity are mainly classified into the super-asymmetric fission model (SAFM) [1] and the preformed cluster model (PCM) [2]. In addition to these models, there are many analytic formulas extracted by fitting the experimental data, such as the Royer formulas [3], the Universal Decay Law (UDL) [4], universal (UNIV) [5], Ren et al. [6] formulas etc. Recently, two studies have been performed on the alpha decays of superheavy nuclei [7,8]. In these Refs., the improved empirical formula and the unified fission model (UFM) with the new  $\alpha$  preformation factor formula have been used respectively to study the alpha decays of superheavy nuclei as well as the predictions of  $\alpha$ -decay half-lives for  $Z=119-120$  isotopes. In this study we propose the shifted Deng-Fan potential, introduced by Deng and Fan to describe diatomic molecules vibrational spectra [9], within the framework of the preformed cluster model (PCM) to investigate the alpha decays of superheavy nuclei using the WKB method [10] and the Bohr-Sommerfeld quantization condition [11].

### Theory

The parent nucleus is considered as a cluster-core system and an effective potential which is the sum of the nuclear, Coulomb and centrifugal potentials, is defined between them. Furthermore, by applying the Wildermuth condition, there is no need to consider the internal structure of the cluster. This condition is given as follows

$$N = 2n + L = \sum_{i=1}^{n_c} (2n_i + \ell_i), \quad (1)$$

in which  $N$  is the global quantum number,  $n_c$  is the total number of the nucleons in the cluster, and  $n_i$  and  $\ell_i$  are quantum numbers of each nucleon in the cluster determined by considering the single-particle shell model configuration. The shifted Deng-Fan potential, as defined below, is proposed as the nuclear potential

$$V_N(r) = V_0 \left(1 - \frac{b}{e^{\alpha r} - 1}\right)^2 - V_0, \quad b = e^{\alpha r_e} - 1, \quad (2)$$

where  $V_0$ ,  $\alpha$  and  $r_e$  are potential parameters that represent the potential depth, the inverse of the potential range and the equilibrium distance between the core and the cluster, respectively. To calculate the half-lives of alpha decays, we apply the WKB method in which the decay width is obtained as follows

$$\Gamma = \lambda_0 F \frac{\hbar^2}{4\mu} P, \quad (3)$$

$$F \int_{r_1}^{r_2} dr \frac{1}{2k(r)} \approx 1, \quad (4)$$

$$P = \exp[-2 \int_{r_2}^{r_3} dr k(r)], \quad (5)$$

and

$$k(r) = \sqrt{\frac{2\mu}{\hbar^2} |Q - V_{eff}(r)|}. \quad (6)$$

$\lambda_0$  is the preformation probability that is unity for even-even emitters,  $Q$  is the decay energy and  $r_1$ ,  $r_2$  and  $r_3$  are the classical turning points determined by the numerical solution of  $V_{eff}(r) = Q$ . In addition we take into account the Bohr-Sommerfeld quantization condition to eliminate the indeterminacy in the depth of the nuclear potential which is given by

$$\int_{r_1}^{r_2} dr k(r) = (N - L + 1) \frac{\pi}{2}, \quad (6)$$



where  $N$  is the global quantum number obtained in terms of the Wildermuth condition (1). Finally the alpha decay half-life is calculated using  $T_{1/2} = \hbar \ln 2 / \Gamma$  relation.

### Results and discussion

The calculated logarithm  $\alpha$ -decay half-lives of even-even superheavy isotopes with  $Z=100-120$  has been shown in Table 1 and compared with the experimental and the recent theoretical results. The columns labeled by IEF [7] and UFM [8] show the results of the improved empirical formula and the unified fission model, respectively, and the last column shows experimental data taken from Ref. [12].

**Table 1.** The calculated logarithm  $\alpha$ -decay half-lives for even-even superheavy nuclei with  $Z=100-120$  as well as the experimental and recent theoretical values.

Parent	Q <sub>α</sub> (MeV) [13]	log <sub>10</sub> T <sub>1/2</sub> (s)			
		Deng-Fan (This work)	IEF [7]	UFM [8]	Exp. [12]
Z=100-118					
<sup>244</sup> Fm	8.55	-0.2849	-0.05	-	-0.11
<sup>248</sup> Fm	8	1.6064	1.76	-	1.56
<sup>252</sup> Fm	7.15	4.9549	4.94	-	4.96
<sup>254</sup> Fm	7.31	4.2823	4.26	-	4.07
<sup>256</sup> Fm	7.03	5.4801	5.40	-	5.07
<sup>254</sup> No	8.23	1.6695	1.69	-	1.75
<sup>256</sup> No	8.58	0.4742	0.45	-	0.46
<sup>258</sup> No	8.15	1.9571	1.87	-	2.08
<sup>256</sup> Rf	8.93	0.1873	0.16	0.13	0.32
<sup>258</sup> Rf	9.19	-0.6332	-0.69	-0.65	-0.98
<sup>260</sup> Rf	8.90	0.2733	0.16	0.31	0.02
<sup>260</sup> Sg	9.9	-1.9015	-2.00	-1.87	-1.91
<sup>264</sup> Hs	10.59	-2.9763	-3.15	-2.83	-2.97
<sup>268</sup> Hs	9.63	-0.3421	-0.62	0.00	0.15
<sup>270</sup> Hs	9.07	1.3892	1.05	1.83	0.95
<sup>270</sup> Ds	11.12	-3.5583	-3.84	-3.15	-3.69
<sup>286</sup> Fl	10.37	-1.1501	-0.80	-0.51	-0.46
<sup>288</sup> Fl	10.07	-0.2962	0.00	0.34	-0.12
<sup>290</sup> Lv	11.01	-2.1257	-1.85	-1.36	-2.10
<sup>292</sup> Lv	10.78	-1.5205	-1.29	-0.73	-1.62
<sup>294</sup> Og	11.84	-2.9660	-3.26	-2.58	-2.94
Z=120					
<sup>296</sup> 120	13.19 [14]	-5.2502	-5.58	-	-
	13.162 [15]	-5.1933	-	-4.69	-
<sup>298</sup> 120	12.90 [14]	-4.6495	-5.03	-	-
	13.089 [15]	-5.0428	-	-4.48	-
<sup>300</sup> 120	13.29 [14]	-5.3500	-5.85	-	-
	13.050 [15]	-4.9615	-	-4.33	-

### Conclusions

As it can be seen from Table 1 the calculated results compare with the other theoretical results and the experimental data show that our proposed potential

model can nicely reproduce the  $\alpha$ -decay half-lives of superheavy nuclei in a phenomenological way and it is a useful tool to provide information for identifying and synthesizing the new superheavy nuclei.

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