α decay of nuclei in extreme cases

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We investigate the recently discovered α decays of heavy and superheavy nuclei with $A=160-294$ by the cluster model of α decay. This covers the short-lifetime α decays of the nuclei near the proton-drip line, the decays of superheavy elements with $Z=106-118$, and the long-lifetime decay of the naturally occurring nuclide ^{180}W [Danevich *et al.*, Phys. Rev. C **67**, 014310 (2003)]. It is found that the cluster model can well reproduce the new data of half-lives of these nuclei. For superheavy nuclei the cluster model, without introducing any additional adjustments, can reasonably reproduce the half-lives of many nuclei although substantial deviations between experimental half-lives and theoretical ones exist in a few cases in which there may be large errors in the experimental data for a single event. Some new α emitters in naturally occurring nuclides are predicted. Experiments to search the α radioactivity of ^{176,178}Hf and of ^{149}Sm are strongly recommended.

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I. INTRODUCTION

α decay is one of the most important decay modes in nuclei. The study on α decay dates back to the early days of nuclear physics. It was first observed as an unknown radiation by Becquerel in 1896 and further studied by Curie, Curie, and Rutherford [1]. Studies on α decay also led to the discoveries of many new elements in the periodic table. This promoted the development of both nuclear physics and chemistry [2]. For a long time the research on α decay concentrated on the heavy nuclei near the stable line and the model of the decay was built based on the data of nuclei in the β-stable valley [3–14]. Recently the experimental development of radioactive beams and of new detector technology under low temperature have made it possible to investigate the α decay in extreme cases. Many new data of the α decay in extreme cases have been reported [15–40]. These studies can be classified into three kinds: (1) to search new α emitters in naturally occurring nuclides, (2) to detect the α decay of nuclei near the proton-drip line, (3) to synthesize new superheavy elements by identifying their α-decay chains. The first kind of studies on α emitters in naturally occurring nuclides involves the nuclei with an exceptional long half-life. The second one on the nuclei near the drip line needs to detect the decay with very short half-life. The third one is very difficult because it requires to measure the α-decay chain in an unknown mass region. Often there are only one or two events of the decay during the some-week run of accelerator for the production of superheavy nuclei. Although more and more new data on α decay have been accumulated in recent years, a systematic comparison between theoretical results and new data is missing due to the fast growth of this field. In this paper we carry out a systematic study on these new data based on the cluster model of α decay. This is an interesting test on the validity of the model in α decay of extreme cases. This paper is also an interesting extension of our previous paper to new mass ranges where we calculated the half-lives of the hindered α decay of some odd-A nuclei near ^{208}Pb within the framework of the cluster model [41].

This paper is organized in the following way. Section II gives the formalism of the α cluster model. We present the numerical results of the α decay of heavy nuclei in Sec. III. Section IV gives a systematic comparison between theoretical half-lives and experimental ones of superheavy elements. A summary is given in Sec. V.

II. THE CLUSTER MODEL OF α DECAY OF NUCLEI

Because the α decay of nuclei is a rich source of nuclear structure information, there are many studies on the phenomenon of α decay. Theoretical physicists used various models [1,5,6,11–14,42–46] to study the favored α decays occurring between the ground states of nuclei. Very old calculations can be found in some textbooks [3,4]. Mang *et al.* [5] developed the microscopic theory of α decay. Rasmussen made a systematic study on the decays of nuclei near the stable line [6]. A review paper on α decays is given in Ref. [7]. Buck and co-workers [12–14] proposed a cluster model of α decay. By using a few parameters they successfully reproduced the experimental data of many nuclei [12–14]. The theoretical half-lives from the cluster model agree with the data of the favored decays within a factor of $2\sim3$ [12–14]. This good agreement between the model and the data is very impressive because experimental half-lives vary in a very wide range from 10^{-9} sec to 10^{19} yr. In this paper we use the cluster model to calculate the new data of half-lives. These include the half-life of the newly observed α emitter ^{180}W, the half-lives of the nuclei near the proton-drip line, and those of recently discovered superheavy nuclei.

The parent nucleus is assumed to be an α particle orbiting the daughter nucleus in the cluster model [12–14]. The orbit of the α particle is denoted by a large value of the global quantum number $G=2n+L$, where n is the node number of radial motion and L is the angular momentum [12–14]. The

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Bohr-Sommerfeld quantization is used to describe the motion of the α particle in a given potential. It is assumed that the α particle is preformed in the parent nucleus and therefore a preformed factor of the α particle is introduced.

In the cluster model the α-core potential [12–14] is

$$V(r) = V_N(r) + V_C(r) + \frac{\hbar^2}{2\mu}\frac{\left(L+\frac{1}{2}\right)^2}{r^2}, \tag{1}$$

where the nuclear potential is given by a "cosh" geometry of depth V_0, diffuseness a, and radius R,

$$V_N(r) = -V_0\frac{1+\cosh(R/a)}{\cosh(r/a)+\cosh(R/a)} \tag{2}$$

and the Coulomb potential is taken to be

$$V_C(r) = \frac{Z_1Z_2e^2}{r} \quad (r \geqslant R),$$
$$= \frac{Z_1Z_2e^2}{2R}\left[3-\left(\frac{r}{R}\right)^2\right] \quad (r \leqslant R), \tag{3}$$

where Z_1 and Z_2 are the charges of the α particle and the core, respectively. A Langer modified centrifugal barrier is used with $L(L+1)$ replaced by $(L+\frac{1}{2})^2$ [12–14].

There are three classical turning points for above potentials and they are denoted as r_1, r_2, and r_3 in order of increasing distance from the origin. Their values are obtained by numerical solutions of the equation $V(r)=Q$. The radius parameter R can be determined separately for each decay by applying the Bohr-Sommerfeld quantization condition:

$$\int_{r_1}^{r_2} dr\sqrt{\frac{2\mu}{\hbar^2}[Q-V_N(r)-V_C(r)]-\frac{\left(L+\frac{1}{2}\right)^2}{r^2}}$$
$$= (2n+1)\frac{\pi}{2} = (G-L+1)\frac{\pi}{2}. \tag{4}$$

In semiclassical approximation, the α-decay width Γ [12–14] is given by

$$\Gamma = PF\frac{\hbar^2}{4\mu}\exp\left[-2\int_{r_2}^{r_3} dr k(r)\right]. \tag{5}$$

The normalization factor F is

$$F\int_{r_1}^{r_2} dr\frac{1}{k(r)}\cos^2\left(\int_{r_1}^{r} dr' k(r') - \frac{\pi}{4}\right) = 1, \tag{6}$$

where the squared cosine term may be replaced by $\frac{1}{2}$ without significant loss of accuracy, so that

$$F\int_{r_1}^{r_2}\frac{dr}{2k(r)} = 1 \tag{7}$$

with the wave number $k(r)$ given by

$$k(r) = \sqrt{\frac{2\mu}{\hbar^2}|Q-V(r)|}. \tag{8}$$

The α-decay half-life is then related to the width by

$$T_{1/2} = \hbar \ln 2/\Gamma. \tag{9}$$

Buck and co-workers [12–14] obtained the values of the parameters in the above potential by a systematic calculation on favored α decays of nuclei. They are $V_0=162.3$ MeV and $a=0.40$ fm [12–14]. The preformation factor of the α cluster [12–14] is chosen to be $P_\alpha=1.0$ for even-even nuclei, $P_\alpha=0.6$ for odd-A nuclei, $P_\alpha=0.35$ for odd-odd nuclei. The values of the global quantum numbers are

$$G = 22 \quad \text{for } N > 126, \tag{10}$$

$$G = 20 \quad \text{for } 82 < N \leqslant 126, \tag{11}$$

$$G = 18 \quad \text{for } N \leqslant 82. \tag{12}$$

In our calculations for the decay of the naturally occurring nuclide ^{180}W and for other cases such as superheavy nuclei, we keep the same inputs as Buck and co-workers [12–14] in order to check the validity of the cluster model for extreme cases.

III. α DECAY OF THE NATURALLY OCCURRING NUCLIDE ^{180}W AND OF THE NUCLEI NEAR THE PROTON-DRIP LINE

Much effort has been made in order to search the α radioactivity of the naturally occurring nuclide ^{180}W [15,47,50]. Macfarlane and Kohman [47] tried to observe the α radioactivity of ^{180}W in 1960 but they failed. Since then efforts to measure the α decay of ^{180}W continued for many years. The successful observation of α decay of ^{180}W has been reported very recently [15]. The half-life of ^{180}W is as long as $T_{1/2}=1.1^{+0.8}_{-0.4}\times10^{18}$ yr [47]. Here we use the cluster model to calculate its half-life. The numerical results of half-lives of ^{180}W and of other nuclei are listed in Table I. In Table I, the first column marks the decay from parent nuclei to daughter ones. The second column shows the experimental decay energies where many of them are taken from the measured values or the values in the mass table [27,40]. Some values of decay energies are deduced from the measured α-particle kinetic energy according to the expression of Buck *et al.* [12]. Experimental half-lives and theoretical ones are given in columns 3 and 4. The experimental values are taken from recent publications where the reference number of each paper is listed in the last column of Table I.

The parent nuclei given in Table I belong to recently observed α decays which have not been investigated by Buck and co-workers [12–14]. It is seen from Table I that the theoretical half-lives are close to experimental ones, with the agreement between the cluster model [12–14] and the data within a factor of 2–3. Here the perfect agreement between the theoretical value and the data of ^{180}W is reached. It is stressed that no addition adjustment is introduced in calculations of half-lives. A favored transition is assumed and ex-

TABLE I. Comparison of theoretical and experimental half-lives of medium nuclei and α-decay half-lives of some naturally occurring nuclei is predicted.

Nuclei	Q_α(expt.) (MeV)	T_α(expt.)	T_α(calc.)	Ref.
$^{180}W \to {}^{176}Hf + \alpha$	2.516 ± 0.005	$1.1^{+0.9}_{-0.5} \times 10^{18}$ yr	1.1×10^{18} yr	[15]
$^{161}Re \to {}^{157}Ta + \alpha$	6.432 ± 0.006	16 ± 1 ms	13 ms	[16]
$^{162}Re \to {}^{158}Ta + \alpha$	6.267 ± 0.005	107 ± 13 ms	92 ms	[17]
$^{162m}Re \to {}^{158m}Ta + \alpha$	6.298 ± 0.005	84.6 ± 6.2 ms	70.4 ms	[17]
$^{166}Pt \to {}^{162}Os + \alpha$	7.314 ± 0.015	0.3 ± 0.1 ms	0.2 ms	[18]
$^{167}Pt \to {}^{163}Os + \alpha$	7.188 ± 0.010	0.7 ± 0.2 ms	0.7 ms	[18]
$^{172}Au \to {}^{168}Ir + \alpha$	7.071 ± 0.009	6.3 ± 1.5 ms	7.8 ms	[19]
$^{174}Hg \to {}^{170}Pt + \alpha$	7.265 ± 0.011	$2.1^{+1.8}_{-0.7}$ ms	1.7 ms	[20]
$^{177}Tl \to {}^{173}Au + \alpha$	7.097 ± 0.007	18 ± 5 ms	25 ms	[21]
$^{177m}Tl \to {}^{173m}Au + \alpha$	7.690 ± 0.013	230 ± 40 μs	359 μs	[21]
$^{180}Tl \to {}^{176}Au + \alpha$	6.537 ± 0.010	1.5 ± 0.3 s	4.3 s	[22]
$^{180}Pb \to {}^{176}Hg + \alpha$	7.446 ± 0.015	4.5 ± 1.1 ms	2.9 ms	[23]
$^{185}Bi \to {}^{181}Tl + \alpha$	8.290 ± 0.030	50 ± 8 μs	44 μs	[24]
$^{188}Po \to {}^{184}Pb + \alpha$	8.119 ± 0.025	400^{+200}_{-150} μs	183 μs	[25]
$^{189}Po \to {}^{185}Pb + \alpha$	7.735 ± 0.020	5 ± 1 ms	4 ms	[25]
$^{190}Po \to {}^{186}Pb + \alpha$	7.744 ± 0.015	$1.9^{+0.6}_{-0.4}$ ms	2.3 ms	[26]
$^{145}Nd \to {}^{141}Ce + \alpha$	1.578 ± 0.002		3.7×10^{22} yr	
$^{149}Sm \to {}^{145}Nd + \alpha$	1.870 ± 0.001		1.9×10^{18} yr	
$^{156}Dy \to {}^{152}Gd + \alpha$	1.757 ± 0.006		3.6×10^{24} yr	
$^{162}Er \to {}^{158}Dy + \alpha$	1.646 ± 0.003		2.8×10^{29} yr	
$^{168}Yb \to {}^{164}Er + \alpha$	1.951 ± 0.004		2.4×10^{24} yr	
$^{176}Hf \to {}^{172}Yb + \alpha$	2.256 ± 0.002		3.0×10^{20} yr	
$^{178}Hf \to {}^{174}Yb + \alpha$	2.083 ± 0.002		4.7×10^{23} yr	
$^{182}W \to {}^{178}Hf + \alpha$	1.774 ± 0.003		4.0×10^{32} yr	
$^{188}Os \to {}^{184}W + \alpha$	2.143 ± 0.002		1.9×10^{26} yr	
$^{192}Pt \to {}^{188}Os + \alpha$	2.418 ± 0.002		1.1×10^{23} yr	
$^{196}Hg \to {}^{192}Pt + \alpha$	2.027 ± 0.004		3.8×10^{32} yr	

perimental decay energy is used for calculations of half-lives. We have also calculated the new data of α decays of other nuclei in Table I where a favored transition with $L=0$ is assumed based on the available data of the spin and parity of the parent nuclei and daughter ones. For example, the ground states of ^{161}Re and ^{157}Ta are known to be $(1/2)^+$ [40]. The ground states of ^{162}Re and ^{158}Ta are 2^- and their first excited states (denoted by the superscript m in Table I) are 9^+ [17,40]. For the transitions between the states of ^{177}Tl and ^{173}Au they also belonged to favored transition because their ground states are $(1/2)^+$ and their first excited states are $(11/2)^-$ [21,40]. Similar arguments hold true for the transitions of other nuclei in Table I (see the corresponding references in Table I and the nuclear mass table [40]). The new data of experimental half-lives can be reproduced within a factor of 2. This is in good agreement with the conclusion of Buck *et al.* on the old data of half-lives [12]. It is demonstrated that the cluster model is valid for the decays of nuclei near the stable line and near the proton-drip line. The half-lives of the decays range from 10^{-6} sec to 10^{18} yr. This is a very wide region. This clearly shows that the cluster model works well for the decays in some extreme cases.

For α-decay half-lives people usually introduce a hindrance factor (HF) to see the difference between experimental half-lives and theoretical ones. The hindrance factor is defined as the ratio of experimental half-lives and theoretical ones $[\mathrm{HF}=T_{1/2}(\mathrm{expt.})/T_{1/2}(\mathrm{theor.})]$. In Fig. 1 we also plot the variation of the HF with nucleon number for $Z=74-84$. It is seen clearly from Fig. 1 that the HF lies between two lines with HF=2.0 and HF=0.5. These two lines form a narrow window within a factor of 2 between experimental half-lives and theoretical ones. The reliability of the cluster model of α decay is systematically tested for these extreme cases.

Because the search for α decay in naturally occurring nuclides is a hot point in recent years, we predict the half-lives of some new α emitters in the lower part of Table I. We consider that the decays from the nuclides ^{149}Sm, ^{156}Dy, ^{168}Yb, ^{176,178}Hf, ^{188}Os, and ^{192}Pt can be easily observed from the point of view of both energy and half-life. So we recommend above seven nuclides as the candidates of new α emitters for future experiments in this mass range. In particular, two experiments are strongly recommended. One is an experiment to search the α decay of ^{149}Sm where the α decay of ^{148}Sm is used as a reference. This is a favored decay between the ground states of ^{149}Sm and ^{145}Nd. The half-life of this decay is appropriate for the observation but its decay

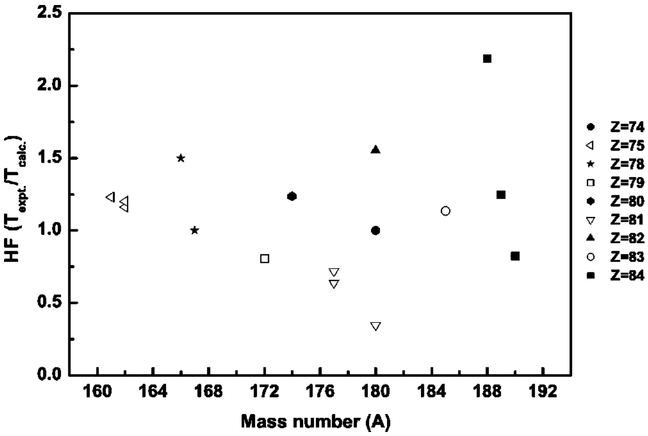

FIG. 1. The variation of the hindrance factor (HF) of α decays with nucleon number for medium and heavy nuclei where HF $=T_{1/2}(\text{expt.})/T_{1/2}(\text{theor.})$

energy is slightly low. Another experiment is to measure the α decays of ^{174,176,178}Hf and this is also very preferable. The half-life of ^{174}Hf is $(2.0\pm0.4)\times10^{15}$ yr. It is known that there is disagreement between the old data of α-decay energy ^{174}Hf (Q_α=2.559 MeV or Q_α=2.584 MeV) [12,47–49] and the data (Q_α=2.495 MeV) from the nuclear mass table [27]. The difference of the decay energies is as high as 0.09 MeV. This difference of decay energies can lead to the change of the half-life of ^{174}Hf by a factor of 10. This uncertainty of the decay energy should be eliminated for the test of the theoretical model of α decay. At first one can measure the decay energy and the half-life of ^{174}Hf to elucidate the difference of decay energies between the old data and that from the mass table. Then one can use same detectors to investigate the decay energy and the half-life of ^{176}Hf where the results of ^{174}Hf are used as a calibration standard. It seems to us that this experiment is available at some laboratories in Orsay and in Kiev [15,50,51]. This will be a very interesting experiment.

IV. α DECAY OF SUPERHEAVY NUCLEI WITH Z=106–118

There is a breakthrough in synthesizing new superheavy nuclides in recent years. The successful synthesis of the elements with Z=110–116 is claimed at GSI in Darmstadt, at JINR in Dubna, and at LBNL in Berkeley. Some of these experiments have been also repeated. For example, the name of the element Z=110 (Ds) is approved by IUPAP and IUPAC. Very recently it is reported that the element Z=118 was produced at JINR in Dubna [52]. Here we present a systematic calculation on the half-lives of superheavy nuclei based on the cluster model. There are two purposes for these calculations. One is to see whether the cluster model works for the superheavy region. Another is to check whether the experimental data themselves are consistent. A significant deviation between the model and the data may also bring an unexpected phenomenon in physics. This is particularly important for superheavy nuclei which lie in a new mass region.

When we calculate the half-lives of superheavy nuclei, we use the same inputs of the cluster model as before. Of course, we should realize that some parameters such as the value of G will change if a wide shell gap appears. The experimental decay energies of superheavy nuclei are used for calculations of theoretical half-lives. Favored transitions are assumed and this is similar to that by Buck and co-workers [12–14]. The numerical results are listed in Table II where quantities have similar meaning to those in Table I. The variation of the HF with nucleon number is drawn in Fig. 2.

Before discussing the numerical results given in Table II and in Fig. 2, we have to stress something on the uncertainty of the experimental data. The experiments on superheavy nuclei are very difficult and therefore the experimental events of the decay are very few. This leads to the uncertainty of experimental half-life and of the decay energy. In some cases only a single event of the decay is observed and the experimental error is not given. We denote the unknown experimental error bar with a mark X in Table II. For the calculations of the half-lives we need to calculate the Q value from the experimental decay energy where the correction of electron shielding is included in the same way as done by Buck and co-workers [12–14]. In our calculations of superheavy nuclei we assume that the decay is a favored transition. This is right for even-even nuclei [27]. For other nuclei, Audi and Wapstra [27] have made a study of the systematic trends of the α-decay energies calculated by assuming feeding of the ground states (see Ref. [27], p. 211). They have also pointed out that for regions of nuclear deformation the favored α transition is known to feed, in daughter nucleus, the level with the same Nilsson level assignments as the parent (see Ref. [27], p. 211). Therefore we use the same approximation in numerical calculations as used by Audi and Wapstra [27].

Let us classify the results of Table II into two parts. The lower part corresponds to the results of nuclei with A=261–268 (Z=106–109). The upper part corresponds to those of nuclei with A=269−294 (Z=110–118). Some of nuclei in the upper part are neutron rich as compared with the nuclei of the lower part.

It is seen from the lower part of Table II that the experimental half-lives can be reproduced by the cluster model within a factor of 2. The nucleon number varies from A=261 (Z=106) to A=268 (Z=109). This is a known range in the superheavy region and the data are widely accepted. The theoretical results agree with experimental ones within a factor 2–3 where no additional adjustment for the superheavy region is introduced in the model. Therefore the cluster model holds well for these neutron-deficient nuclei. This also shows that the experimental data themselves are also consistent.

When we focus on the upper part of Table II (A=269–292 and Z=110–118), we find that there is also reasonable agreement between the theoretical values and the data. The agreement is acceptable for a new mass range where no adjustment on parameters is made, considering also the large experimental error bar due to the difficulty of measurements. In few cases the experimental error bar is still unknown. Totally the theoretical values are close to the data. The ratio (i.e., HF) between experimental half-lives and the-

TABLE II. Comparison of theoretical and experimental half-lives of superheavy nuclei (Z=106–116).

Nuclei	Q_α(expt.) (MeV)	T_α(expt.)	T_α(calc.)	Ref.
$^{294}118 \rightarrow ^{290}116+\alpha$	11.810±0.150	$1.8^{+8.4}_{-0.8}$ ms	2.4 ms	[52]
$^{292}116 \rightarrow ^{288}114+\alpha$	10.757±0.150	33^{+155}_{-15} ms	181 ms	[28]
$^{290}116 \rightarrow ^{286}114+\alpha$	10.860±0.150	29^{+140}_{-33} ms	99 ms	[52]
$^{289}114 \rightarrow ^{285}112+\alpha$	9.895±0.020	30.4±X s	13.7 s	[29]
$^{288}114 \rightarrow ^{284}112+\alpha$	10.028±0.050	$1.9^{+3.3}_{-0.8}$ s	3.5 s	[30]
$^{287}114 \rightarrow ^{283}112+\alpha$	10.484±0.020	5.5^{+10}_{-2} s	0.3 s	[29]
$^{285}112 \rightarrow ^{281}110+\alpha$	8.841±0.020	15.4±X min	79.3 min	[29]
$^{284}112 \rightarrow ^{280}110+\alpha$	9.349±0.050	$9.8^{+18}_{-3.8}$ s	68.2 s	[30]
$^{277}112 \rightarrow ^{273}110+\alpha$	11.666±0.020	240^{+430}_{-90} μs	143 μs	[31]
$^{272}111 \rightarrow ^{268}109+\alpha$	11.029±0.020	$1.5^{+2.0}_{-0.5}$ ms	3.2 ms	[32]
$^{281}110 \rightarrow ^{277}108+\alpha$	9.004±0.020	1.6±X min	4.4 min	[29]
$^{273}110 \rightarrow ^{269}108+\alpha$	11.291±0.020	110±X μs	238 μs	[31]
$^{271}110 \rightarrow ^{267}108+\alpha$	10.958±0.020	0.62±X ms	1.33 ms	[33]
$^{270}110 \rightarrow ^{266}108+\alpha$	11.242±0.050	100^{+140}_{-40} μs	182 μs	[34]
$^{269}110 \rightarrow ^{265}108+\alpha$	11.345±0.020	270^{+1300}_{-120} μs	180 μs	[35]
^{268}Mt$\rightarrow ^{264}107+\alpha$	10.299±0.020	70^{+100}_{-30} ms	43 ms	[32]
^{269}Hs$\rightarrow ^{265}$Sg$+\alpha$	9.354±0.020	7.1±X s	4.3 s	[31]
^{267}Hs$\rightarrow ^{263}$Sg$+\alpha$	10.076±0.020	74±X ms	44 ms	[33]
^{266}Hs$\rightarrow ^{262}$Sg$+\alpha$	10.381±0.020	$2.3^{+1.3}_{-0.6}$ ms	4.5 ms	[34]
^{265}Hs$\rightarrow ^{261}$Sg$+\alpha$	10.777±0.020	583±X μs	842 μs	[35]
^{264}Hs$\rightarrow ^{260}$Sg$+\alpha$	10.590±0.050	0.54±0.30 ms	1.39 ms	[40]
^{267}Bh$\rightarrow ^{263}$Db$+\alpha$	9.009±0.030	17^{+14}_{-6} s	21 s	[37]
^{266}Bh$\rightarrow ^{262}$Db$+\alpha$	9.477±0.020	~1 s	1.5 s	[37]
^{264}Bh$\rightarrow ^{260}$Db$+\alpha$	9.671±0.020	440^{+600}_{-160} ms	425 ms	[32]
^{266}Sg$\rightarrow ^{262}$Rf$+\alpha$	8.836±0.020	25.7±X s	18.9 s	[38]
^{265}Sg$\rightarrow ^{261}$Rf$+\alpha$	8.949±0.020	24.1±X s	14.0 s	[31]
^{263}Sg$\rightarrow ^{259}$Rf$+\alpha$	9.447±0.020	117±X ms	476 ms	[33]
$^{261}Sg\rightarrow ^{257}Rf+\alpha$	9.773±0.020	72±X ms	60 ms	[35]

oretical ones is ≈2–0.5 for many superheavy nuclei (see Table II and Fig. 2). For a few cases the deviation is beyond this range and this may be due to the uncertainty of the measurement of a single decay event. It is expected that the ratio of the experimental half-lives and theoretical ones will lie in the range of $\frac{1}{3}$–3 after the uncertainty of the experimental half-lives is eliminated in future measurements. In short, the agreement between the data of superheavy nuclei and the model is accepted. This shows again that the experimental data themselves are consistent. It suggests that the current experimental statements on the existence of new elements Z=110–118 are reliable.

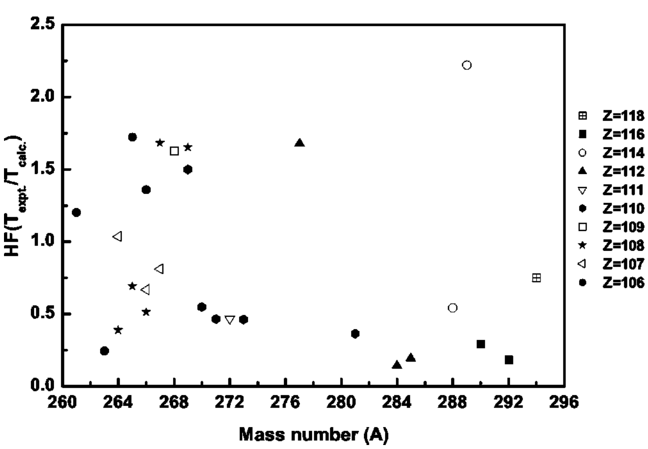

FIG. 2. The variation of the hindrance factor (HF) of α decay with nucleon number for superheavy nuclei with Z=106–118, where HF=$T_{1/2}$(expt.)/$T_{1/2}$(theor.).

The variation of HF with nucleon number is shown in Fig. 2. The agreement between theoretical half-lives and experimental ones is impressive for the superheavy region although substantial deviations exist for a few nuclei. In Fig. 2 the HF of $^{287}114$ is not plotted because its value is beyond the upper border of Fig. 2.

V. SUMMARY

In summary we have calculated the recently discovered α decays of nuclei in some new mass regions using the cluster model of α decay. This includes the newly discovered α emitter of the naturally occurring nuclide ^{180}W, the α decays near the proton drip line, and the decays in superheavy nuclei. This is a systematic test on the validity of the cluster model for decays in extreme cases. In general the model reproduces the half-lives of many α decays of heavy nuclei within a factor of 2–3. This shows that the model holds well for these α emitters. The half-lives of some new α emitters of the naturally occurring nuclides are predicted. New experiments to search the α radioactivity of ^{176,178}Hf and of ^{149}Sm are strongly suggested.

For superheavy nuclei with $Z=106-118$, it is found that theoretical half-lives are close to the experimental ones where no additional adjustment on parameters is introduced. The deviation between experimental half-lives and theoretical ones is approximately a factor of 2–3 for $Z=106-109$ and this precision is very good for this region. For $Z=110-118$ the theoretical results are in reasonable agreement with the data. This shows that the present data of superheavy nuclei themselves are consistent. It could suggest that the present experimental claims on the existence of new elements $Z=110-118$ are reliable. It is expected that greater deviations of a few superheavy nuclei between the data and the model may be eliminated by further improvements on the precision of the measurements.

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