Alpha-decay half-lives and $Q_\alpha$ values of superheavy nuclei

Jianmin Dong,1,2,3 Wei Zuo,1,3 Jianzhong Gu,4 Yanzhao Wang,4 and Bangbao Peng4

1Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China
2Graduate University of Chinese Academy of Sciences, Beijing 100049, China
3School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China
4China Institute of Atomic Energy, P. O. Box 275(18), Beijing 102413, China

(Dated: April 15, 2010)

The $\alpha$-decay half-lives of recently synthesized superheavy nuclei (SHN) are investigated based on a unified fission model (UFM) where a new method to calculate the assault frequency of $\alpha$-emission is used. The excellent agreement with the experimental data indicates the UFM is a useful tool to investigate these $\alpha$-decays. It is found that the half-lives become more and more insensitive to the $Q_\alpha$ values as the atomic number increases on the whole, which is favorable for us to predict the half-lives of SHN. In addition, a formula is suggested to compute the $Q_\alpha$ values for the nuclei with $Z \geq 92$ and $N \geq 140$ with a good accuracy, according to which the long-lived SHN should be neutron rich. With $Q_\alpha$ values from this formula as inputs, we predict the half-lives of isotopes of $Z = 117$, which may be useful for experimental identification in the future.

PACS numbers: 27.90.+b, 21.10.Tg, 23.60.+e

I. INTRODUCTION

Syntheses of superheavy nuclei (SHN) becomes an active and exciting field in modern nuclear physics. Up to now SHN with $Z = 104 – 118$ except $Z = 117$ have been synthesized in experiment. Superheavy elements allow nuclear physicists to explore concepts such as magic numbers and the island of stability, which help us understand the nuclear structure properties in superheavy region. In recent experiments on SHN, on the one hand, $\alpha$-decay is indispensable to the identification of new elements via the observation of $\alpha$-decay from an unknown parent nucleus to a known daughter one since the dominant decay mode for SHN is $\alpha$-decay. On the other hand, experimentalists need the half-life values to design the experiments. Moreover, measurements on the $\alpha$-decays provide reliable information on nuclear structure, such as ground state energies, ground state half-lives, nuclear spins and parities, shell effects, nuclear deformation and shape coexistence [1-3]. Therefore, as one of the most important decay channels for unstable nuclei, $\alpha$-decay has been extensively investigated both experimentally and theoretically. From the theoretical point of view, $\alpha$-decay is regarded as an $\alpha$ particle tunneling through a potential barrier between an $\alpha$ particle and a daughter nucleus, and many theoretical models have been applied to investigate the $\alpha$-decay, such as the cluster model [4-10], generalized liquid drop model (GLDM) [11-12], density-dependent M3Y (DDM3Y) effective interaction [13-15] and coupled channel approach [16-18]. Some physically plausible formulas also have been employed to calculate the $\alpha$-decay half-lives directly [19-23]. A unified fission model (UFM) has been employed to study the proton radioactivity by Balasubramaniam and Arunachalam [24], and it was used to extract the preformation factor of cluster in cluster radioactivity in our previous work [25]. In this work, the UFM [25] is used to study the $\alpha$-decay, in which the assault frequency is treated with a new approach.

It is well known that the most important decay parameters for $\alpha$-decay of SHN are the $Q_\alpha$ value as well as the half-life, and $Q_\alpha$ value is a key factor for the $\alpha$-decay half-life calculation. The half-life is extremely sensitive to the $Q_\alpha$ value and an uncertainty of 1 MeV in $Q_\alpha$ corresponds to an uncertainty of $\alpha$-decay half-life ranging from $10^3$ to $10^5$ times for the heavy element region [26]. Therefore, an accurate formula of $Q_\alpha$ value is crucial for the half-life prediction. However, the calculated $Q_\alpha$ value with the extant methods is difficult to achieve a good accuracy. Therefore, we derive an expression of $Q_\alpha$ value based on the liquid drop model, which can be used as an input to quantitatively predict the half-lives of unknown nuclei.

II. THEORETICAL FRAMEWORK OF THE UFM

The half-life of a parent nucleus decaying via $\alpha$ emission can be calculated by means of the WKB barrier penetration probability. In the UFM, the decay constant is simply defined as $\lambda = \nu_0 P$ and half-life can be obtained by $T = \ln 2/\lambda$. Here $\nu_0$ is the assault frequency which will be addressed in detail later. The barrier penetrability $P$ is given by

$$P = \exp \left[ -\frac{2}{\hbar} \int_{R_{\text{in}}}^{R_{\text{out}}} \sqrt{2\mu (V(r) - Q_\alpha)} dr \right],$$

where $R_{\text{in}}$ and $R_{\text{out}}$ are incoming and outgoing points with $V(R_{\text{in}}) = V(R_{\text{out}}) = Q_\alpha$. The potential $V(r)$ is composed of the repulsive long range Coulomb poten-
tial, the attractive short range nuclear proximity potential and the centrifugal potential for \( r \geq R_1 + R_2 \), but for \( r < R_1 + R_2 \), \( V(r) \) is parameterized simply as a polynomial. Here \( R_0, R_1 \) and \( R_2 \) are the radii of the parent nucleus, daughter one and emitted particle respectively, which are given by \( [36, 38] \)

\[
R_i = (1.28A_i^{1/3} - 0.76 + 0.8A_i^{-1/3}) \text{ fm}, \quad i = 0, 1, 2. \tag{2}
\]

In a word, the potential \( V(r) \) takes the form

\[
V(r) = \begin{cases} 
a_0 + a_1r + a_2r^2 & \text{for } R_0 \leq r < R_1 + R_2 \\
V_p(r) + V_l(r) + \frac{Z_1Z_2e^2}{r} & \text{for } r \geq R_1 + R_2,
\end{cases}
\tag{3}
\]

where \( Z_1 \) and \( Z_2 \) are the charge numbers of the emitted particle and daughter nucleus, respectively. The coefficients \( a_0, a_1, a_2 \) in the polynomial can be determined by the following boundary conditions

1. At \( r = R_0 \), \( V(r) = Q_\alpha \);
2. At \( r = R_1 + R_2 \), \( V(r) = V(R_1 + R_2) \);
3. The third condition ensures the smooth potential curve, which is different from the previous UFM. \( R_{\text{in}} \) is the internal turning point with \( V(r) = Q_\alpha \), which differs from Refs. [35, 39] where the barrier penetration probabilities were calculated from two touching spheres \( (R_{\text{in}} = R_1 + R_2) \). Therefore, the formation process of cluster or \( \alpha \)-particle was not be taken into account and hence one can extract the preformation factor by combining with the experimental half-life. In our calculations with the present potential barrier, however, the penetrability has been evaluated from \( R_{\text{in}} \), hence the process of formation of \( \alpha \)-particle has been considered to a great extent, as has been pointed out in Ref. [40]. The preformation probability can be calculated within a fission model as a penetrability of the internal part of the barrier, which corresponds to still overlapping fragments. \( R_{\text{out}} \) is given by

\[
R_{\text{out}} = \frac{Z_1Z_2e^2}{2Q_\alpha} + \sqrt{\left(\frac{Z_1Z_2e^2}{2Q_\alpha}\right)^2 + \frac{l(l+1)\hbar^2}{2\mu Q_\alpha}}. \tag{4}
\]

\( V_p(r) \) in the potential is the nuclear proximity potential taking the form

\[
V_p(r) = 4\pi \frac{C_1C_2}{C_1 + C_2} \gamma b \Phi(s), \tag{5}
\]

where Süssmann central radii are \( C_i = R_i - b^2/R_i \) and \( b = 0.99 \text{ fm} \) is the surface width. The nuclear surface tension coefficient \( \gamma \) is given as

\[
\gamma = 0.9517 \left[ 1 - 1.7826 \left( \frac{N - Z}{A} \right)^2 \right] \text{ MeV} \cdot \text{fm}^{-2}. \tag{6}
\]

The universal function \( \Phi(s) \) is determined by the following formula \( [36, 38] \)

\[
\Phi(s) = \begin{cases} 
-\frac{1}{4}(s - 2.54)^2 - 0.0852(s - 2.54)^3, & s \leq 1.2511 \\
-3.437\exp\left(-\frac{s - 6.75}{0.75}\right), & s > 1.2511
\end{cases}
\tag{7}
\]

where \( s = (r - C_1 - C_2)/b \) is the overlap distance in units of \( b \) between the colliding surfaces.

We propose a new approach to deal with the assault frequency phenomenologically. Assuming that the \( \alpha \) particle vibrates in a harmonic oscillator potential \( V(r) = -V_0 + \frac{1}{2}\mu \omega^2r^2 \) with a classical frequency \( \omega \) and a reduced mass \( \mu \) after formation, by employing the Virial theorem, we obtain

\[
\mu\omega^2r^2 = (2n_r + l + \frac{3}{2})\hbar\omega, \tag{8}
\]

where \( n_r \) and \( l \) are the radial quantum number (corresponding to the number of nodes) and angular momentum quantum number, respectively. \( \sqrt{r^2} = \langle \psi|\psi \rangle^{1/2} \) is the root-mean-square radius of \( \alpha \) particle distribution in quantum mechanics and that it equals to the rms radius \( R_\alpha \) of nucleus is assumed here. It is farfetched that the assault frequency is understood with a classical method that the \( \alpha \) particle moving back and forth inside the nucleus due to the wave properties of the \( \alpha \) particle. We identify the oscillation frequency \( \nu_0 \) with the assault frequency, which is related to the oscillation frequency \( \omega \)

\[
\nu_0 = \frac{\omega}{2\pi} = \frac{(2n_r + l + \frac{3}{2})\hbar}{2\pi\mu R_\alpha^2} = \frac{(G + \frac{3}{2})\hbar}{1.2\pi\mu R_\alpha^2}. \tag{9}
\]

The relationship of \( R_\alpha^2 = \frac{4}{3}R_0^2 \) [41] is used here. \( G = 2n_r + l \) is the principal quantum number. For \( \alpha \)-decay, we take the form as in Ref. [10]

\[
G = 2n_r + l = \begin{cases} 
22, & N > 126 \\
20, & 82 < N \leq 126 \\
18, & N \leq 82.
\end{cases} \tag{10}
\]

The order of magnitude of \( \nu_0 \) is \( 10^{21} \text{ s}^{-1} \) for \( \alpha \)-decay. As have been pointed out in Ref. [42], the quantum number \( G \) can have an uncertainty of 2 due to the simple application of Wildermuth rule to heavy nuclei that involve shell mixtures, but not serious.

The calculations are performed in the framework of spherical shape, which is partly equivalent to averaging the deformed potential to a spherical case. Recently, some authors investigated the \( \alpha \)-decay in the framework of the deformed version of the \( \alpha \)-decay model. We would point out that the centrifugal barrier should not take the form of \( h^2(l+1/2)^2/(2\mu r^2) \) because \( l \) is not a good quantum number for the deformed potential.

### III. HALF-LIVES OF THE NEWLY SYNTHESIZED SHN

The \( \alpha \)-decay half-lives of SHN calculated with the
UFM using the experimental $Q_\alpha$ values and without considering the centrifugal barrier are given in Table 1. The results obtained with the DDM3Y effective interaction and the GLDM also have been shown for comparison. The results from the UFM are in fair agreement with the experimental data indicating that the UFM taking account of the assault frequency with the phenomenological method is a useful tool to investigate the half-lives of $\alpha$-decay when the experimental $Q_\alpha$ values are given. The DDM3Y effective interaction overestimates but GLDM underestimates the half-lives on the whole. There is no doubt that the DDM3Y interaction and GLDM are very successful due to the appropriate considerations in the microscopic level in the DDM3Y interaction and the quasi-molecular shape in the GLDM. The deviations might result from the fact that empirical assault frequencies they used are too rough. The UFM is given. The DDM3Y effective interaction overestimates and the GLDM also have been shown for comparison.

The deviations might result from the fact that empirical assault frequencies they used are too rough. The UFM is quite simple compared to the GLDM and DDM3Y interaction, but provides the excellent results. Another obvious advantage is that the proximity potential for proton, $\alpha$ and cluster emission can be written in a unified manner, which means these different decay modes can be easily treated in a unified framework. For some nuclei belonging to $^{262,113,260,111}$ and $^{279,111}$ $\alpha$-decay chains, the half-lives from the UFM as well as other models are underestimated by a few times possibly due to the nonzero angular momentum transfers, which reduce the tunneling probability and hence the half-life. However, as no experimental evidence is available for the spin-parity of the levels involved in the decay, we have not included the centrifugal barrier in the calculations.

Recently, the new isotope $^{263}$Hs has been produced in the reaction $^{208}$Pb($^{56}$Fe, n)$^{263}$Hs at the 88-Inch Cyclotron of the Lawrence Berkeley National Laboratory [44]. There are three $\alpha$-particle energy groups at $E_\alpha = 10.57 \pm 0.06$, 10.72 $\pm$ 0.06, and 10.89 $\pm$ 0.06 MeV observed in experiment. The calculated half-life of 0.243 $\pm$ 0.07 ms assuming $E_\alpha = 10.57 \pm 0.06$ MeV ($Q_\alpha = 10.78 \pm 0.06$ MeV) is closest to the experimental data of 0.74 $\pm 0.48$ ms which indicates the group of the $E_\alpha = 10.57 \pm 0.06$ MeV is perhaps the dominant transition among the three groups.

It is an interesting phenomenon that most of odd-A or odd-odd SHN are longer-lived than the even-even ones around them which perhaps indicates the stability of odd-A or odd-odd nuclei over the even-even ones. On the one hand, the small preformation probability could prolong the $\alpha$-decay half-life since the dominant decay mode for SHN is $\alpha$-decay. On the other hand, the possible centrifugal barrier reduces tunneling probability and hence increases the lifetime. This problem needs to be studied further. The odd-A isotopes of all the elements with $Z = 116, 114, 112, 110$ and 108, which lie in the neighborhood of the even-even isotopes, have been observed. This may suggest that $^{293}$118 and $^{295}$118 can be the good candidates to be synthesized in laboratory since the new element $^{294}$118 has been synthesized.

It is well known that the $Q_\alpha$ value is a crucial quantity to determine the $\alpha$-decay half-life. Up to now, however, there has been nearly no approach that can provide an accurate $Q_\alpha$ value theoretically with deviation less than 0.5 MeV, leading to the prediction of half-life with a good accuracy a very difficult work. Here we introduce a quantity

$$K = \left| \frac{\partial \log_{10} T_\alpha(s)}{\partial Q_\alpha} \right|,$$

which describes the $Q_\alpha$ value dependence of $\alpha$-decay half-life. To show the behavior of $K$ values more obviously, we calculate the $K$ values including heavy nuclei ranging from $Z = 62$ to $Z = 118$, and show the results in Fig. 1. One could notice that, the $K$ value decreases with increasing of the atomic number $Z$ on the whole. This indicates the half-life becomes more and more insensitive to $Q_\alpha$ value. For instance, the increase of $Q_\alpha$ value by 0.4 MeV leads to the half-life decrease by only one order of magnitude for $^{294}$118, but five orders of magnitude for $^{147}$Sm. This is an advantage for us to predict the $\alpha$-decay half-lives of SHN since they are not so sensitive to $Q_\alpha$ value as for medium-heavy nuclei. For some nuclei near the $Z = 82$ closure shell, the $K$ values are low because they are strongly affected by the shell effect. We present the $K$ values of even-even Po, Rn, Ra and Th isotopes in Fig. 2. One can find that the larger the atomic number of an element, the lower the $K$ values, which further confirms what we have discussed above. The $K$ value changes smoothly before $N = 126$, but decreases sharply from $N = 126$ to $N = 128$, and increases rapidly after $N = 128$ with increasing of neutron number, indicating the shell effect plays an important role in the behavior of $K$ value. This fact suggests that for a given superheavy element, the isotopes at the beginning of the closed shell are more insensitive to $Q_\alpha$ values.

### IV. FORMULA OF $Q_\alpha$ VALUE FOR NUCLEUS WITH $Z \geq 92$ AND $N \geq 140$

Let us turn to the $Q_\alpha$ value of SHN. The starting point is the local formula of binding energy for the nuclei with $Z \geq 90$ and $N \geq 140$ [45]:

$$B(Z, A) = a_v A - a_x A^{2/3} - a_x Z^2 A^{-1/3} - a_a \left( \frac{A}{2} - Z \right)^2 A^{-1} + a_p A^{-1/2} + a_6 |A - 252|/|A - a_7| |N - 152|/N + a_8 |N - Z - 50|/A.$$

![FIG. 1: $K$ value as a function of atomic number.](image1.png)

![FIG. 2: $K$ values of Po, Rn, Ra and Th isotopes as a function of neutron number.](image2.png)
This formula can achieve a high accuracy for binding energy. However, when it is employed to calculate the $Q_{\alpha}$ value in terms of mass deficit for SHN, the large deviation can be found, as shown in Table III in Ref. [15]. It might be feasible to deduce a more accurate formula for $Q_{\alpha}$ with Eq. (12) because some terms for parent and daughter nuclei may cancel out approximately and contain few parameters. Here we only focus on the nuclei with $Z \geq 92$ and $N \geq 140$. According to Eq. (12), the $Q_{\alpha}$ value can be written as

$$Q_{\alpha} = B(\alpha) + B(Z - 2, A - 4) - B(Z, A)$$

$$= B(\alpha) + [a_{v}(A - 4) - a_{s}A] + \left[a_{v}A^{2/3} - a_{s}(A - 4)^{2/3}\right]$$

$$+ \left[-a_{c}(Z - 2)^{2}(A - 4)^{-1/3} + a_{c}Z^{2}A^{-1/3}\right] +$$

$$\left[-a_{a}\left(\frac{N - Z}{2}\right)^{2}(A - 4)^{-1} + a_{a}\left(\frac{N - Z}{2}\right)^{2}A^{-1}\right]$$

$$+ \left[a_{p}\delta(A - 4)^{-1/2} - a_{p}\delta A^{-1/2}\right] +$$

$$\left[a_{6}\frac{|A - 256|}{A - 4} - a_{6}\frac{|A - 252|}{A}\right] +$$

$$\left[-a_{7}\frac{|N - 154|}{N - 2} + a_{7}\frac{|N - 152|}{N}\right] +$$

$$\left[a_{8}\frac{|N - Z - 50|}{A - 4} - a_{8}\frac{|N - Z - 50|}{A}\right]$$

$$\approx B(\alpha) - 4a_{v} + \frac{8}{3}a_{v}A^{-1/3} + \frac{4}{3}a_{s}Z^{2/3}(3A - Z)$$

$$- a_{a}\left(\frac{N - Z}{A}\right)^{2} + 2a_{p}A^{-3/2} +$$

$$a_{6}\frac{|A - 256|}{A - 4} - a_{6}\frac{|A - 252|}{A} +$$

$$a_{7}\frac{|N - 152|}{N} - a_{7}\frac{|N - 154|}{N - 2} + 4a_{8}\frac{|N - Z - 50|}{A(A - 4)}.$$  (13)

In the process of deduction, the Taylor Expansion was used. As a constant, $B(\alpha)$ is the binding energy of $\alpha$-particle. According to the parameters provided by Ref. [15], we can estimate the contribution from each term. It is found that the pairing energy ($a_{p}$ term), the $a_{6}$ and the $a_{8}$ terms contribute very little to the $Q_{\alpha}$ value and can be neglected. The volume energy ($a_{v}$ term) is only a constant and the surface energy ($a_{s}$ term) can be regarded as a constant since it varies very little in this local region. The term $\alpha_{7}[|N - 152|/N - |N - 154|/(N - 2)]$ simulates the deformed shell effect of $N = 152$. Similarly, we introduce a new term $a_{9}/[Z - Z_{0}] / (Z - |Z - Z_{0} - 2|/(Z - 2))$ to simulate the proton shell effect. We find $Z_{0} = 110$ in our fitting procedure later, which indicates that a possible shell gap exists at $Z = 110$, and we set $Z_{0} = 110$ here beforehand for convenience. Therefore, the above formula can be simplified further to

$$Q_{\alpha}(\text{MeV}) = aZA^{-4/3}(3A - Z) + b\left(\frac{N - Z}{A}\right)^{2}$$

$$+ c\left[\frac{|N - 152|}{N - 2} - \frac{|N - 154|}{N - 2}\right] + d\left[\frac{Z - 110}{Z} - \frac{|Z - 112|}{Z - 2}\right] + e. \quad (14)$$

FIG. 3: The deviations between the formula (14) and experimental $Q_{\alpha}$ values for 154 nuclei with $Z \geq 92$ and $N \geq 140$ as a function of proton number.

The coefficients above are obtained by fitting the 154 experimental data with $Z \geq 92$ and $N \geq 140$. Some experimental data are taken from Ref. [40] and Table I, 260Bh from [47], 237Cm from [48], 258Rf from [49]. That $\alpha$ transitions occur from ground states to ground states is assumed for all decays here. The best fit parameters are

$$a = 0.9373 \text{ MeV}, \quad b = -99.3027 \text{ MeV},$$

$$c = 16.0363 \text{ MeV}, \quad d = -21.5983 \text{ MeV},$$

$$e = -27.4530 \text{ MeV}. \quad (15)$$

The standard and average deviations of the $Q_{\alpha}$ value for the 154 nuclei are as follows

$$\sqrt{\sigma^{2}} = \sqrt{\sum_{i=1}^{154} \frac{1}{154} (Q_{\alpha}^{i} - Q_{\text{cal}}^{i})^{2}} = 0.183, \quad (16)$$

$$\overline{\sigma} = \frac{1}{154} \sum_{i=1}^{154} \frac{1}{154} |Q_{\text{expt.}}^{i} - Q_{\text{cal}}^{i}| = 0.137. \quad (17)$$

The little deviation of $Q_{\alpha}$ value confirms Eq. (14) will be very useful for experiments and it only contains five parameters while Eq. (12) contains eight ones. We plot the deviations between the Eq. (14) and the experimental $Q_{\alpha}$ values in Fig. 3. As Ref. [15] pointed out, $N = 162$ is a magic number since the systematic deviations between theoretical and experimental $Q_{\alpha}$ values near $N = 164$. In a completely analogous manner, systematic deviations in Fig. 3 imply that a possible shell gap exists at $Z = 108$ which has been discussed in many works [50, 51]. From Eq. (14), one can see that the contributions of the coulomb energy and symmetry energy are just opposite, the symmetry energy contributing negatively and much larger than those of shell effects. For long-lived SHN, the $Q_{\alpha}$ value should be smaller, which means the relatively larger absolute symmetry energy for a given element. In other words, long-lived SHN should be neutron rich.
neutron rich SHN is difficult to produce with the existing facilities. However, with the upcoming RIB facilities and improved detection techniques, we believe that such long-lived SHN would be synthesized in the near future.

For the nuclei with $Z \geq 112$, Eq. (14) can give a very good description, hence Eq. (14) can be used to predict the $Q_\alpha$ value with a good accuracy especially for $Z \geq 112$. The $^{282}_{118}$ and $^{293}_{118}$ may be synthesized in the near future, the half-lives of which are predicted to be 0.49 ms and 1.99 ms by employing the UFM with Eq. (14) as inputs. The superheavy element with $Z = 117$ has not been observed in experiment up to now, and some theoretical investigations have been carried out on it $^{52}$. We predict the half-lives of isotopes of $Z = 117$ with the $Q_\alpha$ value from Eq. (14), and the results are listed in table II, which may be useful for future experiments.

V. SUMMARY

In summary, the half-lives of $\alpha$-decay for SHN have been investigated in the framework of a UFM with a new method for assault frequency. No adjustable parameter has been involved in the calculations. The results of the present calculations using the UFM are in excellent agreement with the experimental data. For some nuclei in $^{282}_{113}$, $^{280}_{111}$ and $^{279}_{111}$ $\alpha$-decay chains, the half-lives from the UFM together with other models are underestimated by a few times possibly due to the nonzero angular momentum transfers. We also find that $Q_\alpha$ value dependence of $\alpha$-decay half-life becomes increasing weaker as the atomic number increases on the whole, which implies that the uncertainty of the $\alpha$-decay half-life due to the uncertainty of $Q_\alpha$ value is smaller for heavier nuclei and thus it is exactly what we expect to predict $\alpha$-decay half-life of SHN. And the isotopes at the beginning of the closed shell are more insensitive to $Q_\alpha$ values. Finally, a local formula was proposed to calculate the $Q_\alpha$ values for the nuclei with $Z \geq 92$ and $N \geq 140$. According to this formula in combination with the experimental data, the possible proton shell gaps exist at $Z = 108$ and 110, and long-lived SHN should be neutron rich. The half-lives of isotope of $Z = 117$ which perhaps will be observed in the near future, are predicted by using the UFM combing with this formula.

This work is supported by the National Natural Science Foundation of China (10875151,10575119,10675170,10975190), the Major State Basic Research Developing Program of China under No. 2007CB815003 and 2007CB815004, the Knowledge Innovation Project(KJCX3-SYW-N2) of Chinese Academy of Sciences, CAS/SAFEA International Partnership Program for Creative Research Teams (CXTD-J2005-1).

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TABLE I: Comparisons between the experimental and theoretical α-decay half-lives of recently synthesized superheavy nuclei. The experimental data are from Ref. [13] and the latest data are listed.

| Nucleus | *Q*_α(MeV) | *T*_α(exp) | *T*_α(UFM) | *T*_DDM4Y[24] | *T*_CLDM[18, 23] |
|---------|-------------|-------------|-------------|----------------|-----------------|
| 294118  | 11.81 ± 0.06| 0.89 ±0.01 ms | 0.59 ±0.04 ms | 0.66 ±0.01 ms | 0.155 ±0.004 ms |
| 293116  | 10.67 ± 0.06| 53.62 ±0.01 ms | 43.72 ±0.02 ms | 40.69 ±0.01 ms | 10.45 ±0.005 ms |
| 294116  | 10.80 ± 0.07| 18.50 ±0.01 ms | 14.13 ±0.02 ms | 13.49 ±0.01 ms | 3.47 ±0.009 ms |
| 293116  | 10.89 ± 0.07| 18.52 ±0.01 ms | 26.21 ±0.03 ms | 60.42 ±0.02 ms | 6.35 ±0.010 ms |
| 294116  | 11.00 ± 0.08| 7.13 ±0.01 ms | 14.13 ±0.02 ms | 13.49 ±0.01 ms | 3.47 ±0.009 ms |
| 288115  | 10.61 ± 0.06| 87.30 ±0.01 ms | 72.22 ±0.03 ms | 410.5 ±0.01 ms | 94.7 ±0.009 ms |
| 287115  | 10.74 ± 0.09| 32.135 ±0.01 ms | 33.73 ±0.04 ms | 51.7 ±0.01 ms | 46.0 ±0.013 ms |
| 289114  | 9.96 ± 0.06| 2.73 ±0.01 s | 2.05 ±0.03 s | 3.8 ±0.01 s | 0.52 ±0.005 s |
| 287114  | 10.09 ± 0.07| 0.80 ±0.01 s | 0.89 ±0.01 s | 0.67 ±0.01 s | 0.22 ±0.005 s |
| 286114  | 10.16 ± 0.06| 0.49 ±0.01 s | 0.58 ±0.01 s | 1.13 ±0.01 s | 0.16 ±0.005 s |
| 285114  | 10.33 ± 0.06| 0.13 ±0.01 s | 0.20 ±0.01 s | 0.16 ±0.01 s | 0.05 ±0.005 s |
| 284113  | 10.15 ± 0.06| 0.49 ±0.01 s | 0.30 ±0.01 s | 1.55 ±0.01 s | 0.43 ±0.01 s |
| 283113  | 10.26 ± 0.09| 100.45 ±0.01 ms | 153.3 ±0.01 ms | 201.6 ±0.01 ms | 222.6 ±0.01 ms |
| 282113  | 10.83 ± 0.08a| 23.14 ±0.01 ms | 4.5 ±0.01 ms | 7.8 ±0.01 ms | 7.8 ±0.01 ms |
| 281112  | 9.29 ± 0.06| 3.44 ±0.01 s | 48.0 ±0.01 s | 75.9 ±0.01 s | 13.2 ±0.01 s |
| 280112  | 9.67 ± 0.06| 3.8 ±0.01 s | 3.4 ±0.01 s | 5.9 ±0.01 s | 0.95 ±0.005 s |
| 279111  | 9.87 ± 0.06| 3.6 ±0.01 s | 4.3 ±0.01 s | 4.0 ±0.01 s | 0.67 ±0.005 s |
| 278111  | 10.52 ± 0.16| 170.80 ±0.01 ms | 6.6 ±0.01 ms | 9.6 ±0.01 ms | 12.4 ±0.01 s |
| 277111  | 10.89 ± 0.08a| 4.2 ±0.01 s | 0.79 ±0.01 s | 1.5 ±0.01 s | 1.5 ±0.01 s |
| 275110  | 8.94 ± 0.06| 0.20 ±0.01 s | 0.22 ±0.01 s | 0.40 ±0.01 s | 0.05 ±0.005 s |
| 276109  | 8.85 ± 0.06| 0.72 ±0.01 s | 0.10 ±0.01 s | 0.45 ±0.01 s | 0.19 ±0.005 s |
| 277109  | 10.48 ± 0.09| 9.75 ±0.01 ms | 1.97 ±0.01 ms | 2.75 ±0.01 ms | 4.0 ±0.01 s |
| 276109  | 9.95 ± 0.10a| 440.170 ±0.01 ms | 55.6 ±0.01 ms | 105.5 ±0.01 ms | 105.5 ±0.01 ms |
| 273108  | 9.44 ± 0.06| 0.19 ±0.01 s | 0.70 ±0.01 s | 1.09 ±0.01 s | 0.21 ±0.005 s |
| 274107  | 9.15 ± 0.06| 9.8 ±0.01 s | 2.53 ±0.01 s | 5.4 ±0.01 s | 5.12 ±0.005 s |
| 270107  | 9.11 ± 0.08a| 61.42 ±0.01 ms | 3.6 ±0.01 s | 7.6 ±0.01 s | 7.6 ±0.01 s |
| 271106  | 8.67 ± 0.08| 1.9 ±0.01 min | 0.64 ±0.01 min | 0.86 ±0.01 min | 0.33 ±0.005 min |

*a* _Q*_α_ values are calculated using the measured α kinetic energies.

The electron shielding corrections have been taken into account.

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TABLE II: Predicted α-decay half-lives of Z = 117 isotopes using the UFM with the _Q*_α values from Eq. (14).

| nuclei | _Q*_α(MeV) | _T*_α(UFM) | nuclei | _Q*_α(MeV) | _T*_α(UFM) |
|--------|-------------|-------------|--------|-------------|-------------|
| 288117  | 11.94       | 0.17 ms     | 289117  | 11.81       | 0.53 ms     |
| 290117  | 11.67       | 0.68 ms     | 291117  | 11.54       | 1.34 ms     |
| 292117  | 11.40       | 2.83 ms     | 293117  | 11.27       | 5.73 ms     |
| 294117  | 11.13       | 12.5 ms     | 295117  | 10.99       | 27.5 ms     |
| 296117  | 10.85       | 6.17 ms     | 297117  | 10.71       | 0.14 s      |
| 298117  | 10.57       | 0.33 s      | 299117  | 10.49       | 0.77 s      |
