# $\alpha$-decay half-lives of superheavy nuclei and general predictions*

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**Abstract** The generalized liquid drop model (GLDM) and the cluster model have been employed to calculate the $\alpha$-decay half-lives of superheavy nuclei (SHN) using the experimental $\alpha$-decay $Q$ values. The results of the cluster model are slightly poorer than those from the GLDM if experimental $Q$ values are used. The prediction powers of these two models with theoretical $Q$ values from Audi et al. ($Q_{\rm Audi}$) and Muntian et al. ($Q_{\rm M}$) have been tested to find that the cluster model with $Q_{\rm Audi}$ and $Q_{\rm M}$ could provide reliable results for $Z > 112$ but the GLDM with $Q_{\rm Audi}$ for $Z \leqslant 112$. The half-lives of some still unknown nuclei are predicted by these two models and these results may be useful for future experimental assignment and identification.

**Key words** superheavy nuclei, $\alpha$-decay, half-lives, generalized liquid drop model, cluster model

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## 1 Introduction

The synthesis of superheavy elements has became an attractive topic since the prediction of the existence of superheavy islands in 1960s[1, 2]. With the advent of radioactive ion beam facilities it is now believed that ultimately it would be possible to reach the center of the island of superheavy elements. In experiments one usually measures the decay energies and half-lives while one of the major goals of theory is to be able to predict the $\alpha$-decay half-lives. The $\alpha$-decay of nuclei plays a significant role for providing useful information about nuclei since $\alpha$-decay is one of the most important decay modes for superheavy nuclei. Experimental $\alpha$-decay of superheavy nuclei is one efficient approach to identify new nucleus via the observation of $\alpha$-decay chain from unknown parent nucleus to a known nuclide. Although $\alpha$-decay is very useful for studying the nucleus, the quantitative description of $\alpha$-decay is difficult. The $\alpha$-decay process was first described in 1928[3, 4] according to a quantum tunneling through the potential barrier. Now various phenomenological and microscopical theoretical approaches have been employed to study $\alpha$-decay such as Viola-Seaborg for mulae (VSS)[5], the cluster model[6—9], GLDM[10—16] and density-dependent M3Y (DDM3Y) effective interaction[17, 18]. In the framework of GLDM, the proximity energy term is introduced to correct the potential barrier. In the DDM3Y model, the microscopic nucleus-nucleus potential is obtained by folding the densities of interacting nuclei with the density-dependent M3Y effective nuclear interaction. The cluster model with phenomenological "Cosh" potential is a successful one proposed by Buck and co-workers[6, 7]. The theoretical half-lives from this cluster model agree with the data of the $\alpha$-decay within a factor in the range of 1/3—3[8]. In this work, these two models will be used to calculate the half-lives of SHN and zero angular momentum transfer is assumed.

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## 2 GLDM and cluster model for α-decay half-lives

The GLDM is one of the most successful macroscopic models in describing the process of fusion, fission, lighter nucleus and α-decay. For a deformed nucleus, the macroscopic GLDM energy is defined as[19]

$$E=E_{\rm V}+E_{\rm S}+E_{\rm C}+E_{\rm Rot}+E_{\rm Prox}\,. \tag{1}$$

When the nuclei are separated:

$$E_{\rm V}=-15.494\left[(1-1.8I_1^2)A_1+(1-1.8I_2^2)A_2\right]\ {\rm MeV}, \tag{2}$$

$$E_{\rm S}=17.9439\left[(1-2.6I_1^2)A_1^{2/3}+(1-2.6I_2^2)A_2^{2/3}\right]\ {\rm MeV}, \tag{3}$$

$$E_{\rm C}=0.6e^2Z_1^2/R_1+0.6e^2Z_2^2/R_2+e^2Z_1Z_2/r\,, \tag{4}$$

where $A_i$, $Z_i$, $R_i$ and $I_i$ are the mass number, charge number, radii and relative neutron excesses of the two nuclei. $r$ is the distance between the mass centers. The radii $R_i$ are given by[20]:

$$R_i=(1.28A_i^{1/3}-0.76+0.8A_i^{-1/3})\ {\rm fm}. \tag{5}$$

For one-body shapes, the surface and Coulomb energies are defined as:

$$E_{\rm S}=17.9439(1-2.6I^2)A^{2/3}(S/4\pi R_0^2)\ {\rm MeV}, \tag{6}$$

$$E_{\rm C}=0.6e^2(Z^2/R_0)\times 0.5\int(V(\theta)/V_0)(R(\theta)/R_0)^3\sin\theta{\rm d}\theta. \tag{7}$$

$S$ is the surface of the one-body deformed nucleus. $V(\theta)$ is the electrostatic potential at the surface and $V_0$ the surface potential of the sphere.

The surface energy results from the effects of the surface tension forces in a half space. When there are nucleons in regard in a neck or a gap between separated fragments an additional term called proximity energy must be added to take into account the effects of the nuclear forces between the close surfaces:

$$E_{\rm Prox}(r)=2\gamma\int_{h_{\rm min}}^{h_{\rm max}}\Phi\left[D(r,h)/b\right]2\pi h{\rm d}h, \tag{8}$$

This term is crucial to describe smoothly the one-body to two-body transition and to obtain reasonable fusion barrier heights. The surface parameter $\gamma$ is the geometric mean between the surface parameters of the two nuclei or fragments. $h$ is the distance varying from the neck radius or zero to the height of the neck border. $D$ is the distance between the surfaces in question and $b=0.99$ fm is the surface width. $\Phi$ is the proximity function of Feldmeier[21] and the surface parameter $\gamma$ is the geometric mean between the surface parameters of the two nuclei or fragments.

The half-life of a parent nucleus decaying via α emission is calculated using the WKB barrier penetration probability. The decay constant of the α emitter is simply defined as $\lambda=\nu_0P$. The effective assault frequency $\nu_0$ has been taken as $\nu_0=10^{19}\ {\rm s}^{-1}$[16]. The barrier penetrability $P$ is given by:

$$P=\exp\left[-\frac{2}{\hbar}\int_{R_{\rm in}}^{R_{\rm out}}\sqrt{2B(r)(E(r)-E({\rm sphere}))}{\rm d}r\right]. \tag{9}$$

The deformation energy (relative to sphere) is small until the rupture point between the fragments[14] and the two following approximations have been used: $R_{\rm in}=R_{\rm d}+R_\alpha$ and $B(r)=\mu$ where $\mu$ is the reduced mass. $R_{\rm out}$ is simply $e^2Z_{\rm d}Z_\alpha/Q_\alpha$. The partial half-life is related to the decay constant $\lambda$ by $T_{1/2}=\ln2/\lambda$.

Unlike the GLDM, the cluster model is one of the most successful microscopic models to study α-decay. In this model, the parent nucleus is assumed to be an α particle orbiting the daughter nucleus and the α-core potential $V(r)$ is the sum of the nuclear potential $V_{\rm N}(r)$, the Coulomb potential $V_{\rm C}(r)$ and the centrifugal potential $V_{\rm cen}(r)$[6—8]:

$$V_{\rm N}(r)=-V_0\frac{1+\cosh(R/a)}{\cosh(r/a)+\cosh(R/a)}\,, \tag{10}$$

$$V_{\rm C}(r)=\begin{cases}\dfrac{Z_{\rm e}Z_{\rm d}e^2}{2R}\left[3-\left(\dfrac{r}{R}\right)^2\right] & \text{for } r<R\\ \dfrac{Z_{\rm e}Z_{\rm d}e^2}{r} & \text{otherwise,}\end{cases} \tag{11}$$

$$V_{\rm cen}(r)=\frac{\hbar^2}{2\mu}\frac{\left(L+\frac{1}{2}\right)^2}{r^2}\,, \tag{12}$$

where $Z_{\rm e}$ and $Z_{\rm d}$ are the atomic numbers of the emitted cluster and the daughter nucleus respectively. A Langer modified centrifugal barrier is used with $L(L+1)$ replaced by $(L+1/2)^2$. One can obtain three classical turning points $r_1,r_2,r_3$ by solving the equation $V(r)=Q_\alpha$ and then the radius parameter $R$ can be determined for each decay by employing the Bohr-Sommerfeld quantization condition:

$$\int_{r_1}^{r_2}\sqrt{\frac{2\mu}{\hbar^2}\left[Q-V(r)\right]}\ {\rm d}r=(G-L+1)\frac{\pi}{2}\,. \tag{13}$$

The α-decay width $\Gamma$ can be obtained in semiclassical approximation as long as $R$ is determined:

$$\Gamma=PF\frac{\hbar^2}{4\mu}\exp\left[-2\int_{r_2}^{r_3}K(r){\rm d}r\right], \tag{14}$$

where $P$ is the preformation probability of α particle in parent nucleus. The normalization factor $F$ could be obtained by:

$$F\int_{r_1}^{r_2}\frac{1}{K(r)}\cos^2\left[\int_{r_1}^{r}K(r')\mathrm{d}r'-\frac{\pi}{4}\right]\mathrm{d}r=1\,, \tag{15}$$

where the squared cosine term can be replaced by 0.5 without significant loss of accuracy. The wave number $K(r)$ is given by:

$$K(r)=\sqrt{\frac{2\mu}{\hbar^2}\left|Q-V(r)\right|}\,. \tag{16}$$

With the width $\Gamma$, the α-decay half-life is given by:

$$T_{1/2}=\hbar\ln 2/\Gamma\,. \tag{17}$$

The values of the global quantum numbers are:

$$G=22,\ (N>126), \tag{18}$$

$$G=20,\ (82<N\leqslant 126), \tag{19}$$

$$G=18,\ (N\leqslant 82). \tag{20}$$

Buck and co-workers obtained the values of the parameters in the above potential by a systematic calculation on favored α-decay of nuclei. They obtained $V_0$ = 162.3 MeV and $a$ = 0.40 fm[6, 7]. The preformation probabilities of the α cluster are chosen to be $P_\alpha=1.0$ for even-even nuclei, $P_\alpha=0.6$ for odd-$A$ nuclei and $P_\alpha=0.35$ for odd-odd nuclei[6—8]. But the cluster model does not introduce the assault frequency which is quite different from the GLDM.

Table 1. Comparisons between experimental and theoretical α-decay half-lives for superheavy nuclei using the GLDM and the cluster model (CM) with experimental and theoretical $Q$ values.

| parent nuclei | $Q_{\mathrm{Exp.}}$/ MeV | $Q_{\mathrm{Audi}}$/ MeV | $Q_{\mathrm{M}}$/ MeV | Exp. $T_{\frac{1}{2}}$ | GLDM $T_{\frac{1}{2}}(Q_{\mathrm{Exp.}})$ | CM $T_{\frac{1}{2}}(Q_{\mathrm{Exp.}})$ | GLDM $T_{\frac{1}{2}}(Q_{\mathrm{Audi}})$ | CM $T_{\frac{1}{2}}(Q_{\mathrm{Audi}})$ | GLDM $T_{\frac{1}{2}}(Q_{\mathrm{M}})$ | CM $T_{\frac{1}{2}}(Q_{\mathrm{M}})$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $^{294}$118 | 11.81±0.06 | | 12.11 | $0.89^{+1.07}_{-0.31}$ ms | $0.74^{+0.32}_{-0.19}$ ms | $2.37^{+0.85}_{-0.62}$ ms | | | 0.17 ms | 0.53 ms |
| $^{293}$116 | 10.67±0.06 | | 11.09 | $53^{+62}_{-19}$ ms | $118^{+53}_{-37}$ ms | $503^{+214}_{-150}$ ms | | | 10.1 ms | 45.7 ms |
| $^{292}$116 | 10.80±0.07 | 10.71 | 11.06 | $18^{+16}_{-6}$ ms | $54^{+30}_{-18}$ ms | $141^{+71}_{-47}$ ms | 94.6 ms | 237.8 ms | 12.2 ms | 32.3 ms |
| $^{291}$116 | 10.89±0.07 | 11.00 | 10.91 | $6.3^{+11.6}_{-2.5}$ ms | $33.1^{+16.4}_{-10.9}$ ms | $140^{+69}_{-46}$ ms | 17.7 ms | 75.1 ms | 29.5 ms | 124.7 ms |
| $^{290}$116 | 11.00±0.08 | 11.30 | 11.08 | $15^{+26}_{-6}$ ms | $18.2^{+10.4}_{-6.6}$ ms | $45.0^{+25.5}_{-16.2}$ ms | 3.36 ms | 8.68 ms | 11.6 ms | 28.8 ms |
| $^{288}$115 | 10.61 (6) | 11.00 | 10.95 | $87^{+105}_{-30}$ ms | $94.7^{+41.9}_{-28.9}$ ms | $587^{+251}_{-174}$ ms | 9.41 ms | 63.1 ms | 12.4 ms | 83.4 ms |
| $^{287}$115 | 10.74 (9) | 11.30 | 11.21 | $32^{+155}_{-14}$ ms | $46.0^{+33.1}_{-19.1}$ ms | $160^{+110}_{-65}$ ms | 1.92 ms | 7.20 ms | 3.1 ms | 11.7 ms |
| $^{289}$114 | 9.96±0.06 | 9.85 | 10.04 | $2.7^{+1.4}_{-0.7}$ s | $2.8^{+1.3}_{-0.9}$ s | $9.0^{+4.3}_{-2.9}$ s | 5.81 s | 18.41 s | 1.6 s | 5.4 s |
| $^{288}$114 | 10.09±0.07 | 9.97 | 10.32 | $0.8^{+0.32}_{-0.18}$ s | $1.2^{+0.7}_{-0.4}$ s | $2.34^{+1.32}_{-0.84}$ s | 2.67 s | 5.03 s | 0.27 s | 0.56 s |
| $^{287}$114 | 10.16±0.06 | 10.44 | 10.56 | $0.51^{+0.18}_{-0.10}$ s | $0.81^{+0.39}_{-0.26}$ s | $2.51^{+1.14}_{-0.78}$ s | 0.136 s | 0.45 s | 0.065 s | 0.22 s |
| $^{286}$114 | 10.35±0.06 | 10.70 | 10.86 | $0.13^{+0.04}_{-0.02}$ s | $0.25^{+0.11}_{-0.08}$ s | $0.47^{+0.20}_{-0.15}$ s | 0.03 s | 0.059 s | 0.011 s | 0.24 s |
| $^{284}$113 | 10.15 (6) | 10.25 | 10.68 | $0.48^{+0.58}_{-0.17}$ s | $0.44^{+0.20}_{-0.14}$ s | $2.15^{+0.96}_{-0.67}$ s | 0.23 s | 1.16 s | 0.017 s | 0.091 s |
| $^{283}$113 | 10.26 (9) | 10.60 | 11.12 | $100^{+490}_{-45}$ ms | $222^{+172}_{-96}$ ms | $634^{+466}_{-267}$ ms | 27.1 ms | 84.0 ms | 1.4 ms | 4.7 ms |
| $^{285}$112 | 9.29±0.06 | 8.79 | 9.49 | $34^{+17}_{-9}$ s | $68^{+37}_{-24}$ s | $173^{+92}_{-60}$ s | 49.97 min | 117.5 min | 16.3 s | 42.9 s |
| $^{283}$112 | 9.67±0.06 | 9.62 | 10.16 | $4.0^{+1.3}_{-0.7}$ s | $4.9^{+2.5}_{-1.6}$ s | $12.7^{+6.2}_{-4.2}$ s | 6.93 s | 17.65 s | 0.20 s | 0.55 s |
| $^{280}$111 | 9.87 (6) | 9.98 | 10.77 | $3.6^{+4.3}_{-1.3}$ s | $0.69^{+0.33}_{-0.23}$ s | $2.7^{+1.3}_{-0.9}$ s | 0.335 s | 1.35 s | 0.003 s | 0.013 s |
| $^{279}$111 | 10.52(16) | 10.45 | 11.08 | $170^{+810}_{-80}$ ms | $12.4^{+19.9}_{-7.6}$ ms | $30.9^{+47.5}_{-18.4}$ ms | 18.8 ms | 46.3 ms | 0.53 ms | 1.42 ms |
| $^{279}$110 | 9.84±0.06 | 9.60 | 10.24 | $0.18^{+0.05}_{-0.03}$ s | $0.41^{+0.20}_{-0.13}$ s | $0.89^{+0.41}_{-0.28}$ s | 2.02 s | 4.17 s | 0.032 s | 0.076 s |
| $^{276}$109 | 9.85 (6) | 9.80 | 10.09 | $0.72^{+0.87}_{-0.25}$ s | $0.19^{+0.08}_{-0.06}$ s | $0.66^{+0.30}_{-0.21}$ s | 0.26 s | 0.90 s | 0.041 s | 0.15 s |
| $^{275}$109 | 10.48 (9) | 10.12 | 10.34 | $9.7^{+46}_{-4.4}$ ms | $4.0^{+2.8}_{-1.6}$ ms | $9.0^{+6.0}_{-3.6}$ ms | 35.2 ms | 73.2 ms | 9.1 ms | 20.1 ms |
| $^{275}$108 | 9.44±0.07 | 9.20 | 9.41 | $0.15^{+0.27}_{-0.06}$ s | $1.3^{+0.9}_{-0.5}$ s | $2.48^{+1.47}_{-0.92}$ s | 7.13 s | 12.6 s | 1.7 s | 3.02 s |
| $^{272}$107 | 9.15 (6) | 9.30 | 9.08 | $9.8^{+11.7}_{-3.5}$ s | $5.4^{+2.9}_{-1.9}$ s | $13.6^{+7.0}_{-4.6}$ s | 1.89 s | 4.85 s | 8.9 s | 22.0 s |
| $^{278}$111 | 10.89±0.08 | 10.72 | 11.30 | $1.9^{+2.4}_{-0.6}$ ms | $1.5^{+0.8}_{-0.5}$ ms | $6.7^{+3.7}_{-2.3}$ ms | 3.89 ms | 17.1 ms | 0.17 ms | 0.78 ms |

Table 2. Predictions of the α-decay half-lives using the cluster model (CM), the GLDM and the VSS formulae for superheavy nuclei. The α-decay energies are taken from the extrapolated data of Muntian et al.

| nuclei | $Q$/MeV | $T_{1/2}^{\rm GLDM}$ | $T_{1/2}^{\rm VSS}$ | $T_{1/2}^{\rm CM}$ | nuclei | $Q$/MeV | $T_{1/2}^{\rm GLDM}$ | $T_{1/2}^{\rm VSS}$ | $T_{1/2}^{\rm CM}$ |
|---|---|---|---|---|---|---|---|---|---|
| $^{293}$120 | 13.34 | 2.8 μs | 14.1 μs | 11.8 μs | $^{294}$120 | 13.24 | 3.6 μs | 1.9 μs | 10.8 μs |
| $^{295}$120 | 13.01 | 9.2μs | 64.5 μs | 48.9 μs | $^{296}$120 | 13.23 | 3.5 μs | 2.0 μs | 11.3 μs |
| $^{297}$120 | 13.49 | 1.2 μs | 7.2 μs | 6.3 μs | $^{298}$120 | 13.44 | 1.4μs | 0.78 μs | 4.6 μs |
| $^{299}$120 | 13.23 | 3.2 μs | 23.3 μs | 18.9 μs | $^{300}$120 | 13.11 | 5.3 μs | 3.5 μs | 19.1 μs |
| $^{301}$120 | 13.11 | 5.2μs | 40.5 μs | 31.8 μs | $^{293}$119 | 12.62 | 34 μs | 115 μs | 151 μs |
| $^{294}$119 | 12.38 | 87μs | 827 μs | 796 μs | $^{295}$119 | 12.55 | 40 μs | 162 μs | 209 μs |
| $^{296}$119 | 12.65 | 23μs | 219 μs | 227 μs | $^{297}$119 | 12.86 | 8.7 μs | 36.5 μs | 51.3 μs |
| $^{298}$119 | 12.59 | 29μs | 293 μs | 300 μs | $^{299}$119 | 12.63 | 23 μs | 110 μs | 146 μs |
| $^{290}$118 | 12.40 | 0.052 ms | 0.031 ms | 0.13 ms | $^{291}$118 | 12.24 | 0.11 ms | 0.80 ms | 0.47 ms |
| $^{292}$118 | 12.15 | 0.16 ms | 0.11 ms | 0.44 ms | $^{293}$118 | 11.93 | 0.47 ms | 3.9 ms | 2.16 ms |
| $^{295}$118 | 12.22 | 0.10 ms | 0.89 ms | 0.52 ms | $^{296}$118 | 12.06 | 0.20 ms | 0.17 ms | 0.68 ms |
| $^{297}$118 | 11.91 | 0.40 ms | 4.38 ms | 2.41 ms | $^{298}$118 | 11.98 | 0.28 ms | 0.26 ms | 1.02 ms |
| $^{299}$118 | 11.98 | 0.27 ms | 3.0 ms | 1.7 ms | $^{289}$117 | 11.75 | 0.65 ms | 2.7 ms | 2.7 ms |
| $^{290}$117 | 11.61 | 1.3 ms | 12.6 ms | 9.6 ms | $^{291}$117 | 11.58 | 1.5 ms | 6.8 ms | 6.5 ms |
| $^{292}$117 | 11.42 | 3.4 ms | 35.8 ms | 26.1 ms | $^{293}$117 | 11.53 | 1.8 ms | 8.9 ms | 8.5 ms |
| $^{294}$117 | 11.43 | 2.8 ms | 33.8 ms | 24.8 ms | $^{295}$117 | 11.40 | 3.3 ms | 18.2 ms | 17.1 ms |
| $^{296}$117 | 11.26 | 6.5 ms | 87.7 ms | 62.4 ms | $^{297}$117 | 11.58 | 3.3 ms | 20.3 ms | 19.0 ms |
| $^{286}$116 | 12.39 | 17.4 μs | 9.4 μs | 38.3 μs | $^{287}$116 | 12.00 | 0.10 ms | 0.76 ms | 0.40 ms |
| $^{288}$116 | 11.54 | 1.0 ms | 0.74 ms | 2.4 ms | $^{289}$116 | 11.22 | 5.4 ms | 50.1 ms | 22.2 ms |
| $^{294}$116 | 10.74 | 0.072 s | 0.071 s | 0.20 s | $^{295}$116 | 10.57 | 0.20 s | 2.32 s | 0.91 s |

## 3 Numerical calculations and results

Table 1 shows the recently synthesized SHN and their experimental $Q$ values as well as half-lives. The $Q$ values from the atomic mass evaluation of Audi et al. $(Q_{\rm Audi})$[22] and Muntian et al. $(Q_{\rm M})$[23—25] are also presented, and the theoretical calculations with these $Q$ values are carried out using the GLDM and cluster model. The GLDM provides a better description than the cluster model compared with the experimental half-lives when the experimental $Q$ values are used. The theoretical $Q$ values from Audi et al. which are slightly larger than the experimental ones for $Z>112$ but slightly smaller for $Z\leqslant 112$, are closer to the experimental ones than that from Muntian et al. Unfortunately, most of $Q_{\rm Audi}$ of SHN with $Z>115$ cannot be available. The results show that the half-lives obtained with the cluster model with $Q_{\rm Audi}$ are in best agreement with the experimental data for $Z>112$ and more accurate than that using the experimental $Q$ values, and the cluster model with $Q_{\rm M}$ could also provide satisfactory results only slightly poorer than those with $Q_{\rm Audi}$. The cluster model overestimates the half-lives when the experimental $Q$ values are used but the $Q_{\rm Audi}$ and $Q_{\rm M}$ overestimate the $Q$ values for $Z>112$. Consequently, the wonderful half-lives are obtained for $Z>112$, which indicates the predictive power of the cluster model connecting with $Q_{\rm Audi}$ and $Q_{\rm M}$. But the GLDM is able to provide results agreeing with the experimental half-lives for $Z\leqslant 112$ but smaller than the experimental ones for $Z>112$ when $Q_{\rm Audi}$ are employed. The differences between the results obtained with the GLDM and the cluster model are not very large (only a few times) in the above calculations on the whole.

Both advantages and disadvantages can be found in the GLDM as well as the cluster model. As a macroscopic model, the GLDM does not take account of microscopic information sufficiently, such as the preformation probability, the quantum assault frequency and the shell correction, but it can be extended easily to investigate the cluster emission since the proximity energy is described by an unified formula (8). As a microscopic model, the cluster model introduces the preformation factor and does not need to introduce the assault frequency, but its nuclear potential is experiential and difficult to generalize. However, the two quite different models are capable of providing the same trend and anear results. Thus, they can validate each other, and more compelling results can be obtained. Here we predict the half-lives of some SHN within these two models, the results being presented in Table 2 and Table 3. The results of the cluster model are almost always larger than those of the GLDM ones in current calculations and this difference decreases with decreased $Z$, but almost always smaller than that from the VSS formulae. These results may be useful for future experiments.

Table 3. Predictions of the α-decay half-lives using the cluster model (CM), the GLDM and the VSS formulae for superheavy nuclei. The α-decay energies are taken from the extrapolated data of Audi et al.

| nuclei | $Q$/MeV | $T_{1/2}^{\rm GLDM}$ | $T_{1/2}^{\rm VSS}$ | $T_{1/2}^{\rm CM}$ | nuclei | $Q$/MeV | $T_{1/2}^{\rm GLDM}$ | $T_{1/2}^{\rm VSS}$ | $T_{1/2}^{\rm CM}$ |
|---|---|---|---|---|---|---|---|---|---|
| $^{293}118$ | 12.30 | 77 μs | 592 μs | 356 μs | $^{292}117$ | 11.60 | 1.30 ms | 13.33 ms | 10.1 ms |
| $^{291}117$ | 11.90 | 0.29 ms | 1.23 ms | 1.29 ms | $^{291}115$ | 10.00 | 4.33 s | 21.9 s | 15.0 s |
| $^{290}115$ | 10.30 | 0.62 s | 6.86 s | 3.83 s | $^{289}116$ | 11.70 | 0.43 ms | 3.63 ms | 1.8 ms |
| $^{289}115$ | 10.60 | 0.097 s | 0.48 s | 0.36 s | $^{287}113$ | 9.34 | 102 s | 461 s | 272 s |
| $^{286}113$ | 9.68 | 9.44 s | 92.5 s | 44.6 s | $^{285}114$ | 11.00 | 5.1 ms | 44.6 ms | 18.1 ms |
| $^{285}113$ | 10.02 | 0.99 s | 4.35 s | 2.83 s | $^{284}112$ | 9.30 | 64.7s | 47.3 s | 97.3 s |
| $^{283}111$ | 8.96 | 6.01 min | 25.73 min | 13.93 min | $^{282}112$ | 9.96 | 0.77 s | 0.52 s | 1.15 s |
| $^{282}111$ | 9.38 | 18.6 s | 158.4 s | 70.3 s | $^{281}112$ | 10.28 | 0.102 s | 0.786 s | 0.266 s |
| $^{281}111$ | 9.64 | 3.1 s | 12.0 s | 7.0 s | $^{281}110$ | 8.96 | 3.05 min | 22.47 min | 6.05 min |
| $^{280}112$ | 10.62 | 13.3 ms | 8.62 ms | 21.7 ms | $^{280}110$ | 9.30 | 15.5 s | 9.76 s | 19.1 s |
| $^{279}112$ | 10.96 | 2.1 ms | 14.1 ms | 5.4 ms | $^{279}109$ | 8.70 | 10.35 min | 36.32 min | 18.41 min |
| $^{278}112$ | 11.38 | 0.22 ms | 0.12 ms | 0.36 ms | $^{278}110$ | 10.00 | 149 ms | 90 ms | 195 ms |
| $^{278}109$ | 9.10 | 31.0 s | 239.7 s | 98.8 s | $^{277}112$ | 11.62 | 0.069 ms | 0.402 ms | 0.179 ms |
| $^{277}111$ | 11.18 | 0.323 ms | 1.073 ms | 0.84 ms | $^{277}110$ | 10.30 | 23.1 ms | 162 ms | 53.2 ms |
| $^{277}109$ | 9.50 | 1.89 s | 6.61 s | 3.67 s | $^{277}108$ | 8.40 | 49.7 min | 330.3 min | 81.6 min |
| $^{276}111$ | 11.32 | 0.157 ms | 1.11 ms | 0.70 ms | $^{276}110$ | 10.60 | 4.0 ms | 2.4 ms | 5.7 ms |
| $^{276}108$ | 8.80 | 131 s | 75 s | 134 s | $^{275}111$ | 11.55 | 51.5 μs | 152 μs | 129 μs |
| $^{275}110$ | 11.10 | 0.26 ms | 1.65 ms | 0.64 ms | $^{274}110$ | 11.40 | 55.5 μs | 28.7 μs | 82.7 μs |
| $^{274}108$ | 9.50 | 0.92 s | 0.51 s | 1.0 s | $^{274}107$ | 8.50 | 9.94 min | 70.98 min | 26.6 min |
| $^{273}111$ | 11.20 | 0.33 ms | 0.96 ms | 0.75 ms | $^{273}110$ | 11.37 | 0.067 ms | 0.39 ms | 0.16 ms |
| $^{273}109$ | 10.82 | 0.61 ms | 1.96 ms | 1.38 ms | $^{273}108$ | 9.90 | 69.4 ms | 441.6 ms | 130.4 ms |
| $^{273}107$ | 8.90 | 28.8 s | 92.8 s | 46.3 s | $^{272}111$ | 11.44 | 0.11 ms | 0.59 ms | 0.38 ms |
| $^{272}110$ | 10.76 | 1.97 ms | 0.94 ms | 2.33 ms | $^{272}109$ | 10.60 | 2.34 ms | 15.02 ms | 7.85 ms |
| $^{272}108$ | 10.10 | 21.7 ms | 10.9 ms | 23.3 ms | $^{271}107$ | 9.50 | 0.499 s | 1.40 s | 0.75 s |
| $^{272}106$ | 8.30 | 24.9 min | 11.4 min | 18.9 min | $^{271}110$ | 10.87 | 1.12 ms | 5.86 ms | 2.13 ms |
| $^{271}109$ | 10.14 | 37.5 ms | 105.6 ms | 64.5 ms | $^{271}108$ | 9.90 | 79.2 ms | 441.7 ms | 130 ms |
| $^{270}110$ | 11.20 | 0.199 ms | 0.083 ms | 0.225 ms | $^{270}109$ | 10.35 | 10.7 ms | 65 ms | 32.2 ms |
| $^{270}106$ | 9.10 | 3.59 s | 1.66 s | 2.96 s | $^{270}105$ | 8.20 | 24.38 min | 140.53 min | 50.09 min |
| $^{269}110$ | 11.58 | 30 μs | 132 μs | 56 μs | $^{269}109$ | 10.53 | 3.8 ms | 10.3 ms | 6.7 ms |
| $^{269}108$ | 9.63 | 0.48 s | 2.52 s | 0.71 s | $^{269}107$ | 8.84 | 55.9 s | 144.5 s | 71.0 s |
| $^{269}106$ | 8.80 | 32.5 s | 167.9 s | 41.3 s | $^{269}105$ | 8.40 | 4.96 min | 12.93 min | 5.97 min |
| $^{268}110$ | 11.92 | 6.3 μs | 2.1 μs | 6.8 μs | $^{268}109$ | 10.73 | 1.28 ms | 7.15 ms | 3.80 ms |
| $^{268}108$ | 9.90 | 85.7 ms | 37.7 ms | 77.5 ms | $^{268}107$ | 9.08 | 9.86 s | 55.5 s | 21.8 s |
| $^{268}106$ | 8.40 | 12.1 min | 5.1 min | 8.5 min | $^{268}105$ | 8.20 | 25.4 min | 140.5 min | 49.8 min |
| $^{268}104$ | 8.10 | 23.8 min | 10.2 min | 16.2 min | $^{267}110$ | 12.28 | 1.3 μs | 4.4 μs | 2.2 μs |
| $^{267}109$ | 10.87 | 0.61 ms | 1.49 ms | 1.04 ms | $^{267}108$ | 10.12 | 22.1 ms | 112.5 ms | 34.2 ms |
| $^{267}107$ | 9.37 | 1.33 s | 3.36 s | 1.76 s | $^{267}106$ | 8.64 | 1.9 min | 9.3 min | 2.2 min |
| $^{267}105$ | 7.90 | 330 min | 787 min | 351 min | $^{266}106$ | 8.88 | 19.3s | 8.0 s | 13.8 s |
| $^{265}109$ | 11.07 | 0.22 ms | 0.50 ms | 0.36 ms | $^{265}108$ | 10.59 | 1.47 ms | 7.00 ms | 2.32 ms |
| $^{265}107$ | 9.77 | 99.7ms | 241 ms | 133.4 ms | $^{265}106$ | 9.08 | 4.7 s | 22.2 s | 5.6 s |
| $^{265}105$ | 8.49 | 2.70 min | 6.43 min | 2.96 min | $^{264}107$ | 9.97 | 29.9 ms | 151 ms | 67.3 ms |
| $^{264}108$ | 10.59 | 1.58 ms | 0.60 ms | 1.38 ms | $^{264}105$ | 8.66 | 46.1 s | 232 s | 84.7 s |
| $^{264}106$ | 9.21 | 1.99 s | 0.77 s | 1.37 s | $^{263}108$ | 10.67 | 1.03 ms | 4.45 ms | 1.49 ms |
| $^{263}107$ | 10.08 | 15.5 ms | 34.9 ms | 20.3 ms | $^{263}106$ | 9.39 | 0.60 s | 2.64 s | 0.69 s |
| $^{263}105$ | 9.01 | 3.7 s | 8.3 s | 4.0 s | $^{262}105$ | 9.01 | 4.1s | 18.2 s | 6.9 s |
| $^{262}107$ | 10.30 | 4.4 ms | 20.5 ms | 9.7 ms | $^{262}106$ | 9.60 | 160.4 ms | 56.7 ms | 106.8 ms |
| $^{261}107$ | 10.56 | 1.04 ms | 2.07 ms | 1.33 ms | $^{261}106$ | 9.80 | 44.8 ms | 183.9 ms | 51.2 ms |
| $^{261}105$ | 9.22 | 0.96 s | 1.92 s | 0.96 s | $^{260}105$ | 9.38 | 0.33 s | 1.44 s | 0.57 s |
| $^{260}107$ | 10.47 | 1.77 ms | 7.62 ms | 3.72ms | $^{260}106$ | 9.92 | 21.9 ms | 7.48 ms | 14.8 ms |
| $^{259}106$ | 9.83 | 39.4 ms | 152.3 ms | 42.5 ms | $^{259}105$ | 9.62 | 69.0 ms | 136.7 ms | 72.0 ms |
| $^{258}106$ | 9.67 | 114 ms | 36 ms | 68.3 ms | $^{258}105$ | 9.48 | 0.18s | 0.74 s | 0.30 s |
| $^{257}105$ | 9.23 | 1.0 s | 1.8 s | 0.89 s | $^{256}105$ | 9.46 | 230ms | 848 ms | 336 ms |

## 4 Summary

The half-lives of recently synthesized SHN have been calculated in the framework of the GLDM and the cluster model with experimental $Q$ values. The results of the GLDM are better than those of the cluster model if experimental $Q$ values are used. But it is more reliable to predict the half-lives of SHN within the cluster model for $Z > 112$ with ($Q_{\rm Audi}$) and ($Q_{\rm M}$) while using the GLDM with ($Q_{\rm Audi}$) for $Z \leqslant 112$. Predictions are also made using these two models with $Q_{\rm Audi}$ and $Q_{\rm M}$. These results may be useful for future experimental assignment and identification.

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