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Systematic study of new data for extreme α decays

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Recently discovered α decays with new or improved data, covering naturally occurring α emitters with long lifetimes, short-lived ones approaching the proton drip line, and decays of heavy and superheavy elements, have been studied in a systematic investigation within the modified two-potential approach for deformed nuclei by constructing the microscopic double-folding potential. It is found that the experimental half-lives are well reproduced in the density-dependent cluster model. Some predictions on natural α emitters and α decays of several proton emitters are made in this study. Moreover, the α-decay half-lives of even-even superheavy nuclei with $Z = 110$–114 and $N = 184$–194 are estimated to pursue the quite stable nuclei around the proton $Z \sim 114$ and neutron $N \sim 184$ shell closures. These predictions can be useful for future experiments aimed at searching for long-lived natural elements.

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I. INTRODUCTION

One century ago, Marie and Pierre Curie identified two new elements via the observation of their strong radioactivity [1]. Before long, Rutherford and Geiger first recognized α decay in an experiment in 1908 [2]. Subsequently, more new elements were discovered by α-decay studies, promoting the development of both nuclear physics and chemistry. With the improvement of experimental facilities, more attention has been paid to long-lived natural α emitters. In the 1960s, there were measurements of natural α radioactivity in medium-mass elements by using cylindrical ionization counters to accommodate samples [3]. Similar research has been concentrated on natural α decay since then. Recently, much effort has been focused on probing the natural α decay of ^{180}W [4–6], and there is also additional research on the α radioactivity of natural europium [7]. Besides naturally occurring α emitters, plenty of unstable nuclei have been produced artificially in nuclear reactions. Within the fusion-evaporation reactions, considerable experimental data on α emissions for various isotopes close to the proton drip line have been acquired for the first time or with improved accuracy [8–15], including the recent discovery of the new nuclide ^{161}Os [15]. In fact, some neutron-deficient isotopes approaching the proton drip line were originally produced to pursue new cases of proton emission [8]. Moreover, along with α decay, interesting phenomena such as shape coexistence and intruder states have also been observed in the region around the $Z = 82$ shell closure and the $N = 104$ midshell [9,10,16]. Recently, in a series of experiments performed with the velocity filter SHIP, new or improved α-decay data of neutron-deficient isotopes of heavier elements were obtained by the reactions of isotopically enriched material of $^{204,206-208}$Pb and natural ^{209}Bi with ^{36}S, ^{48}Ca, ^{54}Cr, ^{58}Fe, and ^{50}Ti beams [17–20]. Besides, new isotopes such as $^{274-x,277}$Hs and ^{285}114 have been produced in the evaporation channel of the hot-fusion reaction [21–23].

The above decay data just belong to some extreme cases: long-lived α emitters in naturally occurring nuclides, exotic nuclei close to the proton drip line with short lifetimes, and newly synthesized heavy and superheavy nuclei. Interestingly, these experimental achievements on extreme α decays may provide some unique information on nuclear structure [39]. There is no doubt that it is of great interest and importance to present a reasonable description of these new α-decay data. In turn, they also offer an opportunity to test theoretical models sternly and extend the research region. Until now, based on various theoretical models such as the cluster model, the shell model, and the fissionlike model, many investigations have been performed on α-decay properties [24–42]. Very recently, we have employed the modified two-potential approach (MTPA), based on perturbation theory, to give a description of α decay [43–45]. The MTPA can consistently reach the achievement that a tunneling problem is essentially simplified by reducing it into two separate problems: a bound-state problem and a scattering-state problem [46]. Within the cluster model, the α-decay half-lives have been evaluated by using this approach for a wide range of nuclei, including α decays of exotic nuclei around the $N = 126$ shell closure [43] and those of medium-mass nuclei [44]. We also extend the MTPA for deformed nuclei (MTPADN) to investigate the α decay in the heavy and superheavy region [45]. These calculated α-decay half-lives are found to be in good agreement with the experimental data. As a further test and extension of our previous work, the present study reports a systematic calculation of these extreme α decays with a number of new data obtained using the MTPADN, and we also make some predictions on half-lives of unknown α emitters.

This paper is organized as follows. The theoretical framework of the MTPADN associated with the density-dependent

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cluster model is briefly described in Sec. II. In Sec. III, comparison of our calculations with measured data is made, some predictions on α emissions in natural nuclides and light nuclei near the proton drip line are made, and the "island of stability" in superheavy nuclei is discussed to some extent. A summary is given in Sec. IV.

II. THE MODIFIED TWO-POTENTIAL APPROACH FOR DEFORMED NUCLEI WITHIN THE DENSITY-DEPENDENT CLUSTER MODEL

By assuming an α particle interacts with an axially symmetric deformed daughter nucleus, the nuclear and Coulomb potentials are microscopically constructed by the double-folding model,

$$V_{\mathrm{N\,or\,C}}(\mathbf{r},\theta)=\iint d\mathbf{r_1}d\mathbf{r_2}\rho_1(\mathbf{r_1})\upsilon(\mathbf{s}=|\mathbf{r_2}+\mathbf{r}-\mathbf{r_1}|)\rho_2(\mathbf{r_2}). \tag{1}$$

Here θ is the orientation angle of the emitted α particle with respect to the symmetric axis of the axially deformed daughter nucleus, and $\upsilon(\mathbf{s})$ is the realistic M3Y-Reid-type nucleon-nucleon interaction or the standard Coulomb proton-proton interaction. Different from the standard Gaussian density distribution ρ_1 of the spherical α particle, ρ_2 of the core nucleus is described in a deformed Fermi form,

$$\rho_2(r_2,\theta)=\frac{\rho_0}{1+\exp\left[\frac{r_2-R(\theta)}{a}\right]}, \tag{2}$$

where $R(\theta)=R_0[1+\beta_2Y_{20}(\theta)+\beta_4Y_{40}(\theta)]$, and the ρ_0 value is determined by integrating the density distribution equivalent to the mass and atomic numbers of the corresponding daughter nucleus (respectively for the nuclear and Coulomb potentials). The quadrupole and hexadecapole deformation parameters β_2 and β_4 are taken from the theoretical values calculated by Möller *et al.* [47]. The details of the effective interaction and the choice of the parameters in the potential such as half-density radius R_0 and diffuseness a can be found in Refs. [48, 49]. After the double-folding potential is numerically obtained by using the multipole expansion, the total potential of the spherical-deformed interacting system, comprising the nuclear and Coulomb potentials plus the centrifugal part, is given by

$$V(r,\theta)=\lambda V_N(r,\theta)+V_C(r,\theta)+\frac{\hbar^2\ell(\ell+1)}{2\mu r^2}, \tag{3}$$

where the renormalization factor λ is the depth of the nuclear potential, μ is the reduced mass of the α-daughter system, and ℓ is the angular momentum carried by the α particle. By considering one certain orientation angle θ, the axially symmetric potential $V(r,\theta)$ can be reduced to $V(r)$, i.e., the one-dimensional case. Then the two-potential approach presents the potential as a sum of an "inner" term and an "outer" term by a separation radius R, which is taken reasonably inside the potential barrier. Subsequently, one can introduce two auxiliary potentials according to the MTPA [31,46]: the inner one,

$$U(r)=\begin{cases}V(r), & r\leqslant R, \quad (4a)\\ V(R)=V_0, & r>R, \quad (4b)\end{cases}$$

and the outer one,

$$W(r)=\begin{cases}0, & r\leqslant R, \quad (5a)\\ V(r)-V_0, & r>R. \quad (5b)\end{cases}$$

Note that the "shifted" potential $\tilde{W}(r)=W(r)+V_0$, disregarding the case $r\to\infty$, is actually introduced to solve the eigenproblem perturbatively [46]. Within the inner potential $U(r)$, the radial Schrödinger equation is numerically solved for the bound-state wave function $\phi_{n\ell j}(r)$, which vanishes sharply exponentially from the separation radius R [45]. Following previous studies, the depth of the nuclear potential λ is fixed to adjust the experimental Q value. The special quantum number n [or, say, the number of nodes of the bound-state wave function $\phi_{n\ell j}(r)$] is determined by the Wildermuth condition [50], by taking into account the main effect of the Pauli principle. Moreover, its remaining effect is largely absorbed into the fit for the parameters of the effective α-nucleus potential, and a zero-potential term for the single-nucleon exchange in the M3Y interaction guarantees the antisymmetrization of identical nucleons in the α cluster and the daughter nucleus [42,48,49]. Ultimately, one can obtain the decay width $\Gamma(\theta)$ in the MTPA for a certain angle θ (see details in Refs. [45,46]). By averaging $\Gamma(\theta)$ in all directions [38], the final decay width is achieved:

$$\Gamma=\int_0^{\pi/2}\Gamma(\theta)\sin(\theta)d\theta. \tag{6}$$

Then the α-decay half-life related to the decay width is given by

$$T_{1/2}=\frac{\hbar\ln2}{P_\alpha\Gamma}, \tag{7}$$

where the indispensable quantity P_α, describing the α-preformation probability in the parent nucleus, is introduced into the calculation. Experimentally, it is shown that the preformation factor P_α varies smoothly in the open-shell region and has a value smaller than 1 [51]. Hence we take the preformation factor as the same constant for one kind of nucleus, i.e., $P_\alpha^{\text{even-even}}=0.41$, $P_\alpha^{\text{odd-}A}=0.27$, and $P_\alpha^{\text{odd-odd}}=0.16$. These values are identical with previous systematic calculations [44,45], and they agree well with the microscopic calculation of the typical nucleus ^{212}Po [32].

III. NUMERICAL RESULTS AND DISCUSSION

We have performed a systematic calculation on the extreme α decays of the recent experiments in this study. As mentioned before, these α transitions are divided into three extreme cases: heavier nuclei, naturally occurring nuclides, and α emitters close to the proton drip line. In contemporary nuclear physics, the synthesis of new superheavy elements (SHEs) is a hot and attractive topic. Especially, the very recent synthesis of the

TABLE I. Comparison of the calculated α-decay half-lives with the measured values in the recent experiments for heavier nuclei, including new isotopes or new data with improved accuracy.

Nuclei	Q (MeV)	$T_{1/2}^{\mathrm{expt}}$	$T_{1/2}^{\mathrm{calc}}$
$^{289}114$	10.01(3)	$2.1^{+0.8}_{-0.4}$ s [21]	3.1 s
$^{288}114$	10.09(3)	$0.69^{+0.17}_{-0.11}$ s [21]	1.05 s
$^{285}112$	9.34(3)	29^{+11}_{-6} s [21]	60 s
^{281}Ds	8.88(3)	144^{+250}_{-12} s [21]	260 s
^{265}Hs	10.588(15)	$1.7^{+1.7}_{-0.6}$ ms [17]	1.3 ms
^{263}Hs	11.06(6)	$0.74^{+0.48}_{-0.21}$ ms [20]	0.38 ms
^{262}Bh	9.839(15)	83 ± 14 ms [17]	68 ms
^{261}Bh	$\approx$10.16	$11.8^{+3.9}_{-2.4}$ ms [18]	5.6 ms
^{267}Sg	8.32(5)	471^{+353}_{-118} s [22]	593 s
^{265}Sg	8.82(5)	15^{+7}_{-4} s [22]	14 s
^{260}Sg	9.900(10)	4.95 ± 0.33 ms [17]	6.53 ms
^{257}Db	9.300(20)	0.67 ± 0.6 s [17]	0.27 s
^{253}Lr	8.859(20)	1.32 ± 0.14 s [17]	1.09 s
^{249}Md	8.157(10)	23 ± 3 s [17]	37 s
^{237}Cf	8.220(20)	1.14 ± 0.29 s [19]	2.06 s
^{236}Cm	7.074(20)	2278 ± 278 s [19]	2602 s
^{233}Cm	7.473(20)	164^{+93}_{-43} s [19]	155 s
$^{293}117$	11.18(8)	14^{+11}_{-4} ms [53]	11 ms
$^{289}115$	10.45(9)	$0.22^{+0.26}_{-0.08}$ s [53]	0.43 s
$^{285}113$	9.88(8)	$5.5^{+5.0}_{-1.8}$ s [53]	3.5 s
$^{294}117$	10.96(10)	78^{+370}_{-36} ms [53]	147 ms
$^{290}115$	10.09(40)	16^{+75}_{-8} ms [53]	7.3 s
$^{286}113$	9.76(10)	20^{+94}_{-9} s [53]	13 s
^{282}Sg	9.13(10)	$0.51^{+2.5}_{-0.23}$ s [53]	209.77 s
^{278}Mt	9.69(19)	$7.7^{+37}_{-3.5}$ s [53]	0.7 s
^{274}Bh	8.93(10)	53^{+250}_{-24} s [53]	26 s

new isotopes $^{293,294}117$ [52,53] fills the final gap to $Z = 118$ in the nuclide chart. Given that α decay is the primary decay mode of SHEs, the observation of α-decay chains has been a reliable tool to identify new SHEs and new isomeric states. The new experiments in Darmstadt, Berkeley, and Dubna [17–23] provide a perfect opportunity to test the present α-decay study strictly, and this study may in turn check whether these measured values such as decay energies and half-lives in these α-decay chains are consistent with each other to some extent. The detailed numerical results for the newly observed α decay of heavier nuclei are listed in Table I. It is to be noted that the angular momentum of the emitted α particle for superheavy nuclei is assumed as $\ell = 0$ (i.e., favored α transitions), due to the limited knowledge of the level schemes in the superheavy mass region. The experimental error bar is also relatively large in the measurement of decay energies and half-lives due to experimental difficulties and the paucity of observed decay events. Nevertheless, the measured α-decay half-lives are well reproduced, as can be seen from Table I, except for $^{290}115$ and ^{282}Rg of the α-decay chain originating from the new isotope $^{294}117$, resulting in the slightly large error bar in this experiment. For example, the experimental error bar of the Q value for $^{290}115$ is 0.4 MeV, which could cause large uncertainty in the calculation of the α-decay half-life and is therefore worth further investigation. These two α-decay chains originating from the element $Z = 117$ were actually investigated in our previous work [45]. However, the present work employs the double-folding model to construct nuclear and Coulomb potentials and pursue a more microscopic understanding. In addition, Oganessian *et al.* have presented more details on the α decay of these nine new isotopes very recently [53]. With these in mind, we also give systematic calculations on the newly observed α-decay chains from the new SHE $Z = 117$.

As is well known, the possibility of the existence of an "island of stability" in the region $Z \sim 114$ and $N \sim 184$ was proposed in the 1960s. Ever since then, attempts to probe the possible existence of this region in nature have been made

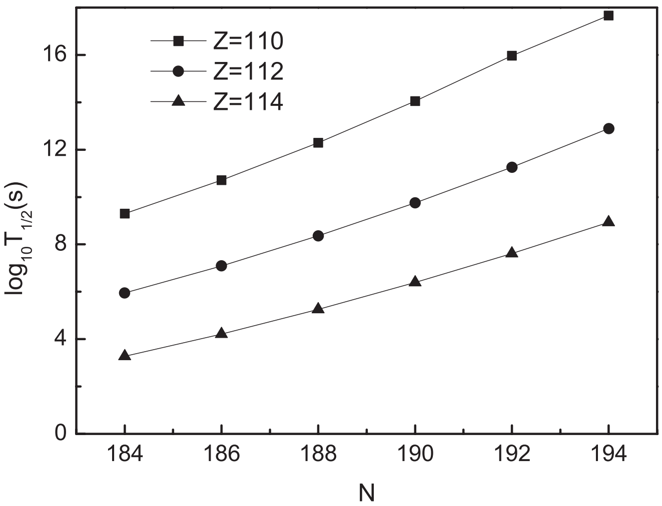

FIG. 1. Decimal logarithm of α-decay half-lives vs the neutron number N for even-even superheavy nuclei of $Z = 110$–114 isotopes from $N = 184$ to $N = 194$, indicating the enhancement of the lifetime against α decay with increasing N value. Note that the decay energy is estimated by the formula in Ref. [57].

using various approaches (see Refs. [54–56] and references therein). After an α-decay calculation for ^{294}110 with a quite long half-life was performed, a specific search with accelerator mass spectrometry for this isotope was initiated in 1980 on a platinum nugget [54]. Very recently, some experiments with more sensitive facilities have been employed to search for long-lived SHE isotopes in natural materials [55,56]. Given the good agreement between experiment and theory for these new α-decay data, the half-lives of ground-state-to-ground-state α decays for even-even superheavy nuclei in $Z = 110$–114 isotopes from $N = 184$ to $N = 194$ have been estimated by using a recent Q_α formula proposed by Dong and Ren [57], in order to probe the possibility of the existence of SHE nuclides with half-lives greater than 150 million years ($\sim 5 \times 10^{15}$ s) [56]. As shown in Fig. 1, the plot of $\log_{10} T_{1/2}$ of these superheavy nuclei versus the neutron number N for an isotopic chain shows an increase because of the decrease of decay energy Q with the increase of neutron number N. This enhancement of half-life is slightly beyond the standard systematics, and this is interesting for future research. According to these predictions on superheavy nuclei, quite stable α emitters among the heaviest nuclei may exist to the northwest of the nuclide chart with respect to ^{298}114, which may be helpful for future experiments on the search for long-lived superheavy nuclides in nature.

There are also naturally occurring α-decay nuclides with long lifetimes in the lighter mass region, which are usually in the vicinity of the line of stability. These studies may provide us with further knowledge of the line of stability. Although the newly reported data of these nuclides are relatively few, they can check the validity of the present MTPADN approach for α decay with quite long half-lives corresponding to quite narrow decay widths. The details on these calculations and predictions for possible candidates, including the newly observed nuclides ^{180}W and ^{151}Eu, are displayed in Table II. Note that these studied α emitters are generally even-even nuclei and decay from ground states to ground states. The spins and parities of parent nuclei and corresponding daughter nuclei are also identical for a few odd-A emitters [58]. Consequently, the α decays are generally treated as favored transitions here. In contrast, the ground-state-to-ground-state transition of ^{151}Eu is assigned as $5/2^+ \rightarrow 7/2^+$ according to Ref. [7]. It is found that the available experimental data are well reproduced, and other calculated half-lives are in general larger than the lower limit [58]. For ^{184}Os and ^{151}Eu, calculated α-decay half-lives are slightly smaller compared to expected values [7,58]. This is worth further investigation, especially for ^{184}Os without the experimental observation of α decay. In fact, the calculated α-decay half-lives of some nuclides are small enough to relatively easily overcome difficulty in experimental measurement, and modern equipment is becoming more and more sensitive. Moreover, there actually exists an uncertainty for the Q value of ^{174}Hf (see Ref. [39] and references therein). Given these facts, we strongly recommend searching the three nuclides ^{149}Sm and ^{174,176}Hf for α decay.

Table III demonstrates the systematic calculation on the new data of α transitions from ground and isomeric states approaching the proton drip line. Different from Tables I and II, the transitions from I_i^π to I_f^π are displayed in the second column. As one can see, these α decays prefer to be favored ones (i.e., $\ell = 0$) by choosing the smallest value obeying the spin-parity selection rule, no matter whether the parent nuclei are ground states or low-lying isomeric states. In fact, the spin and parity cannot be unambiguously determined due to the unpaired nucleons for the case of odd-A and odd-odd nuclei. Some detailed decay schemes are deduced tentatively based on the available experimental cases [8–13]. On the other hand, tentative assignments of the spin and parity for some isotopes are taken from the systematic trends in neighboring nuclides [58]. Within these tentative assignments of the spin and parity, recent experimental α-decay half-lives are successfully reproduced. Hence these tentative assignments and the assumption of favored α decays appear to be reasonable. Especially for the new isotopes ^{161}Os and ^{165}Re, the calculated α-decay half-lives are consistent with the newly measured values, which may in turn be considered as proof of the reliability of these experimental data. We also make predictions on the α decay of the light proton emitters ^{109}I and ^{112,113}Cs. Experimentally, the half-lives for proton emissions of these three nuclei are, respectively, 103 ± 5 μs [60], 500 ± 100 μs [61], and $16.7 \pm 0.7 \mu$s [62], which are much smaller in contrast with those predicted α-decay half-lives (see Table III). This indicates that the α-decay branch for these light proton emitters is very small, corresponding to the large hindrance for α decay. The situation may be caused by the larger Coulomb barrier of α transition for these light nuclei compared to that of proton emission. Meanwhile, the block effect of odd nucleons on the formation of α particles may be considered as another reason resulting in the very large ratio of proton emission to α decay for ^{109}I, ^{112}Cs, and ^{113}Cs. Generally, for either narrow or large decay width, these available data of extreme α decays are well reproduced within a mean factor of about 2, as shown in Tables I, II, and III. This means that the MTPADN within the density-dependent

TABLE II. Same as Table I but for naturally occurring α emitters with long lifetimes, including many predictions. Note that the available experimental data are mainly taken from Refs. [58,59] besides the recent data for ^{151}Eu and ^{180}W [4,7], and the measured value of ^{174}Hf is taken from Ref. [3].

Decay	Q (MeV)	$T_{1/2}^{\mathrm{expt}}$ (years)	$T_{1/2}^{\mathrm{calc}}$ (years)
^{142}Ce→^{138}Ba	1.310	$>5\times10^{16}$	6.54×10^{27}
^{146}Sm→^{142}Nd	2.529	$1.03\pm0.05\times10^{8}$	1.27×10^{8}
^{147}Sm→^{143}Nd	2.310	$1.06\pm0.02\times10^{11}$	1.50×10^{11}
^{148}Sm→^{144}Nd	1.986	$7.00\pm2.00\times10^{15}$	9.36×10^{15}
^{149}Sm→^{145}Nd	1.870	$>2\times10^{15}$	3.02×10^{18}
^{151}Eu→^{145}Pm	1.964	$\geqslant1.7\times10^{18}$	1.26×10^{18}
^{152}Gd→^{148}Sm	2.205	$1.08\pm0.08\times10^{14}$	1.10×10^{14}
^{156}Dy→^{152}Gd	1.758	$>1.0\times10^{15}$	5.46×10^{24}
^{162}Er→^{158}Dy	1.645	$>1.4\times10^{14}$	3.49×10^{29}
^{164}Er→^{160}Dy	1.304		1.60×10^{40}
^{168}Yb→^{164}Er	1.950	$>1.3\times10^{14}$	2.57×10^{24}
^{174}Hf→^{170}Yb	2.559	$2.00\pm0.40\times10^{15}$	4.02×10^{15}
^{176}Hf→^{172}Yb	2.258		1.18×10^{20}
^{180}W→^{176}Hf	2.516	$1.1^{+0.9}_{-0.5}\times10^{18}$	0.82×10^{18}
^{184}Os→^{180}W	2.957	$>5.6\times10^{13}$	3.51×10^{13}
^{188}Os→^{184}W	2.143		1.45×10^{26}
^{190}Pt→^{186}Os	3.243	$6.50\pm0.30\times10^{11}$	5.46×10^{11}
^{192}Pt→^{188}Os	2.418	$>6\times10^{16}$	9.05×10^{22}
^{196}Hg→^{192}Pt	2.041	$>2.5\times10^{18}$	1.76×10^{32}
^{204}Pb→^{200}Hg	1.970	$\geqslant1.4\times10^{17}$	7.36×10^{36}
^{238}U→^{234}Th	4.270	$5.656\pm0.004\times10^{9}$	1.520×10^{10}
^{244}Pu→^{240}U	4.666	$1.007\pm0.004\times10^{8}$	1.417×10^{8}

TABLE III. Comparison of the calculated α-decay half-lives with the new data for some neutron-deficient nuclei near the proton drip line. Note that these α transitions are all considered as favored ones, and the symbol # denotes the tentative assignment from the systematic trends in neighboring nuclides [58].

Decay	$I_i^{\pi}\to I_f^{\pi}$	Q (MeV)	$T_{1/2}^{\mathrm{expt}}$	$T_{1/2}^{\mathrm{calc}}$
^{109}I→^{105}Sb	$5/2^+\to5/2^+$	3.835		98.7 ms
^{112}Cs→^{108}I	$1^+\to1^+$#	3.710		10.2 s
^{113}Cs→^{109}I	$5/2^+\to5/2^+$#	3.430		633 s
^{159}Re→^{155}Ta	$11/2^-\to11/2^-$	6.951	280 ± 53 μs [8]	247 μs
^{161}Os→^{157}W	$7/2^-\to7/2^-$#	6.890	677 ± 63 μs [15]	810 μs
^{167}Ir→^{163}Re	$1/2^+\to1/2^+$	6.504	71.9 ± 3.0 ms [13]	66.2 ms
^{167}Ir^m→^{163}Re^m	$11/2^-\to11/2^-$	6.561	31.8 ± 3.7 ms [13]	40.9 ms
^{169}Ir→^{165}Re	$1/2^+\to1/2^+$	6.138	840 ± 10 ms [13]	1507 ms
^{169}Ir^m→^{165}Re^m	$11/2^-\to11/2^-$	6.265	475 ± 5 ms [13]	472 ms
^{172}Pt→^{168}Os	$0^+\to0^+$	6.475	103 ± 20 ms [11]	133 ms
^{172}Au→^{168}Ir	$3^-\to3^-$#	6.923	22^{+6}_{-4} ms [14]	24 ms
^{172}Au^m→^{168}Ir	$9^+\to9^+$#	7.034	13^{+3}_{-1} ms [14]	10 ms
^{175}Au^m→^{171}Ir^m	$11/2^-\to11/2^-$	6.583	153 ± 6 ms [12]	205 ms
^{177}Au→^{173}Ir	$(1/2^+,3/2^+)\to(3/2^+,5/2^+)$	6.303	3.83 ± 0.18 s [10]	2.23 s
^{177}Au^m→^{173}Ir^m	$11/2^-\to11/2^-$	6.266	1.52 ± 0.30 s [10]	3.15 s
^{176}Hg→^{172}Pt	$0^+\to0^+$	6.917	21 ± 3 ms [11]	25 ms
^{179}Tl^m→^{175}Au^m	$11/2^-\to11/2^-$	7.372	1.46 ± 0.04 ms [12]	1.96 ms
^{181}Tl^m→^{177}Au^m	$9/2^-\to9/2^-$	6.727	365 ± 8 ms [10]	429 ms
^{179}Pb→^{175}Hg^m	$9/2^-\to9/2^-$	7.518	$3.5^{+1.4}_{-0.8}$ ms [12]	2.8 ms
^{180}Pb→^{176}Hg	$0^+\to0^+$	7.419	4.2 ± 0.5 ms [11]	3.6 ms
^{181}Pb→^{177}Hg^m	$9/2^-\to9/2^-$	7.175	36 ± 2 ms [11]	34 ms
^{187}Bi→^{183}Tl^m	$9/2^-\to9/2^-$	7.153	45 ± 2 ms [9]	94 ms
^{187}Bi^m→^{183}Tl	$1/2^+\to1/2^+$	7.890	0.37 ± 0.02 ms [9]	0.24 ms
^{187}Po→^{183}Pb^m	$(1/2^-,5/2^-)\to(1/2^-,5/2^-)$	7.693	1.40 ± 0.25 ms [9]	1.70 ms

cluster model can give a reasonable description of α decay in extreme cases. Moreover, the validity of the present approach encourages us to give some predictions on α emissions near the line of stability and the proton drip line.

IV. SUMMARY

In conclusion, the MTPA for deformed nuclei associated with the density-dependent cluster model is used to give systematic calculations on new data of recently observed α decays of long- and short-lived α emitters and heavy and superheavy nuclei. The good agreement between experiment and theory can be considered as a further proof for the validity of the present approach, and it also encourages us to make some predictions. Some naturally occurring nuclides are predicted as candidates of long-lived α emitters near the line of stability. Especially, investigations of α decays of the nuclides ^{149}Sm, ^{174,176}Hf, and ^{184}Os are strongly recommended for future experiments. In addition, the α-decay half-lives of even-even superheavy nuclei of $Z = 110$–114 isotopes in the range of $N = 184$–194 are calculated to pursue knowledge of the "island of stability", which is expected to probe the SHEs with half-lives greater than about 150 million years. This may be helpful for the search of long-lived SHEs in natural materials. We also hope that the predicted values of some proton emitters just beyond the double-magic nucleus ^{100}Sn can be used to compare with future experiments.

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