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Alpha decay half-lives of heavy nuclei within a generalized liquid drop model*

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Abstract Theoretical α-decay half-lives of the heaviest nuclei are calculated using the experimental Q_α value. The barriers in the quasi-molecular shape path is determined within a Generalized Liquid Drop Model (GLDM) and the WKB approximation is used. The results are compared with calculations using the Density-Dependent M3Y (DDM3Y) effective interaction and the Viola-Seaborg-Sobiczewski (VSS) formulae. The calculations provide consistent estimates for the half-lives of the α decay chains of these superheavy elements. The experimental data stand between the GLDM calculations and VSS ones in the most time.

Key words generalized liquid drop model, alpha decay energy, half-life

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1 Introduction

The possibility to synthesize superheavy elements by cold or warm fusion reactions[1—3] using radioactive ion beams has renewed interest in investigating the fusion barriers. The main observed decay mode of these heaviest systems is the α emission, and an accurate description of the α decay is required. The pure Coulomb barrier sharply peaked at the touching point alone does not allow to determine correctly the fusion cross sections and the partialα decay half-lives. In the fusion path, the nucleon-nucleon forces act before the formation of a neck between the two quasispherical colliding ions and a proximity energy term must be added in the usual development of the liquid-drop model[4]. It is highly probable that the α decay takes place also in this fusion-like deformation valley where the one-body shape keeps quasi-spherical ends while the transition between one and two-body configurations corresponds to two spherical nuclei in contact. Consequently, the proximity energy term plays also a main role to correctly describe the α decay barrier. The generalized liquid drop model (GLDM) which includes such a proximity energy term has allowed to describe the fusion[5], fission[6], light nucleus [7] and α emission [8] processes. The formation and alpha decay of superheavy elements have been investigated[9] in taking into account the experimental Q_α value or the value provided by the Thomas-Fermi model[10].

This paper is organized in the following way. The theoretical α decay lifetimes from different models and detailed discussions are given in Sect. 2. We reserve our summary in Sect. 3.

2 Numerical calculations and discussions

The GLDM energy is widely explained in Ref.[11] and not recalled here. The half-life of the parent nucleus decaying via α emission is calculated using the WKB barrier penetration probability. The α decay half-lives of the recently produced heaviest nuclei calculated with the GLDM using the experimental Q_α value and without considering the rotational contribution are presented in Table 1. The results agree reasonably with the experimental data indicat-

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ing that the GLDM taking account the proximity effects, the mass asymmetry, and an accurate nuclear radius is sufficient to reproduce the α decay potential barriers when the experimental Q_α value is known. The results obtained with the DDM3Y interaction agree with the experimental data as the GLDM predictions and largely better than the VSS calculations. This shows that a double folding potential obtained using M3Y[12] effective interaction supplemented by a zero-range potential for the single-nucleon exchange is very appropriate because its microscopic nature includes many nuclear features, in particular a potential energy surface is inherently embedded in this description. This double agreement shows that the experimental data themselves seem to be consistent. For most nuclei the predictions of the VSS model largely overestimate the half lives.

The half live of $^{294}118$ is slightly underestimated in the three theoretical calculations possibly due to the neutron submagic number $N=176$. In Ref.[13], it is also pointed out that for oblate deformed chain of $Z=112$, the shell closure appears at $N=176$.

Table 1. Comparison between experimental α decay half-lives and results obtained with the GLDM, the DDM3Y effective interaction and the VSS formulae for the heaviest nuclei.

parent	nuclei	Expt.	Expt.	DDM3Y	GLDM	VSS
Z	A	Q/MeV	$T_{1/2}$	$T_{1/2}$	$T_{1/2}$	$T_{1/2}$
118	294	11.81 ± 0.06	$1.8^{+75}_{-1.3}$ ms	$0.66^{+0.23}_{-0.18}$ ms	$0.15^{+0.05}_{-0.04}$ ms	$0.64^{+0.24}_{-0.18}$ ms
116	293	10.67 ± 0.06	53^{+62}_{-19} ms	206^{+90}_{-61} ms	$22.81^{+10.22}_{-7.06}$ ms	1258^{+557}_{-384} ms
116	292	10.80 ± 0.07	18^{+16}_{-6} ms	39^{+20}_{-13} ms	$10.45^{+5.65}_{-3.45}$ ms	49^{+26}_{-16} ms
116	291	10.89 ± 0.07	$6.3^{+11.6}_{-2.5}$ ms	$60.4^{+30.2}_{-20.1}$ ms	$6.35^{+3.15}_{-2.08}$ ms	$336.4^{+173.1}_{-113.4}$ ms
116	290	11.00 ± 0.08	15^{+26}_{-6} ms	$13.4^{+7.7}_{-5.2}$ ms	$3.47^{+1.99}_{-1.26}$ ms	$15.2^{+9.0}_{-5.6}$ ms
114	289	9.96 ± 0.06	$2.7^{+1.4}_{-0.7}$ s	$3.8^{+1.8}_{-1.2}$ s	$0.52^{+0.25}_{-0.17}$ s	$26.7^{+13.1}_{-8.7}$ s
114	288	10.09 ± 0.07	$0.8^{+0.32}_{-0.18}$ s	$0.67^{+0.37}_{-0.27}$ s	$0.22^{+0.12}_{-0.08}$ s	$0.98^{+0.56}_{-0.40}$ s
114	287	10.16 ± 0.06	$0.51^{+0.18}_{-0.10}$ s	$1.13^{+0.52}_{-0.40}$ s	$0.16^{+0.08}_{-0.05}$ s	$7.24^{+3.43}_{-2.61}$ s
114	286	10.35 ± 0.06	$0.16^{+0.07}_{-0.03}$ s	$0.14^{+0.06}_{-0.04}$ s	$0.05^{+0.02}_{-0.02}$ s	$0.19^{+0.08}_{-0.06}$ s
112	285	9.29 ± 0.06	34^{+17}_{-9} s	75^{+41}_{-26} s	$13.22^{+7.25}_{-4.64}$ s	592^{+323}_{-207} s
112	283	9.67 ± 0.06	$4.0^{+1.3}_{-0.7}$ s	$5.9^{+2.9}_{-2.0}$ s	$0.95^{+0.48}_{-0.32}$ s	$41.3^{+20.9}_{-13.8}$ s
110	279	9.84 ± 0.06	$0.18^{+0.05}_{-0.03}$ s	$0.40^{+0.18}_{-0.13}$ s	$0.08^{+0.04}_{-0.02}$ s	$2.92^{+1.4}_{-0.94}$ s
108	275	9.44 ± 0.07	$0.15^{+0.27}_{-0.06}$ s	$1.09^{+0.73}_{-0.40}$ s	$0.27^{+0.16}_{-0.10}$ s	$8.98^{+5.49}_{-3.38}$ s
106	271	8.65 ± 0.08	$2.4^{+4.3}_{-1.0}$ min	$1.0^{+0.8}_{-0.5}$ min	$0.33^{+0.28}_{-0.16}$ min	$8.6^{+7.3}_{-3.9}$ min

Table 2. Comparison between experimental α decay half-lives and results obtained with the GLDM, the DDM3Y effective interaction and the VSS formulae for the heaviest odd-Z nuclei.

parent	Expt.	Ref.[23]	Expt.	DDM3Y	GLDM	GLDM	VSS	VSS
nuclei	Q/MeV	Q/MeV	$T_{1/2}$	$T_{1/2}(Q_{\rm ex})$	$T_{1/2}(Q_{\rm ex})$	$T_{1/2}(Q_{\rm Audi})$	$T_{1/2}(Q_{\rm ex})$	$T_{1/2}(Q_{\rm Audi})$
$^{288}115$	10.61 (6)		$87\ ^{+105}_{-30}$ ms	409 ms	$94.7^{+41.9}_{-28.9}$ ms		997^{+442}_{-303} ms	
$^{284}113$	10.15 (6)	10.25	$0.48^{+0.58}_{-0.17}$ s	$1.55^{+0.72}_{-0.48}$s	$0.43^{+0.21}_{-0.13}$ s	0.23 s	$4.13^{+1.94}_{-1.31}$ s	2.19 s
$^{280}111$	9.87 (6)	9.98	$3.6\ ^{+4.3}_{-1.3}$ s	$1.9^{+0.9}_{-0.6}$ s	$0.69^{+0.33}_{-0.23}$ s	0.34 s	$5.70^{+2.74}_{-1.84}$ s	2.79 s
$^{276}109$	9.85 (6)	9.80	$0.72^{+0.87}_{-0.25}$ s	$0.45^{+0.23}_{-0.14}$s	$0.19^{+0.08}_{-0.06}$ s	0.26 s	$1.44^{+0.68}_{-0.46}$ s	1.99 s
$^{272}107$	9.15 (6)	9.30	$9.8^{+11.7}_{-3.5}$ s	$10.1^{+5.4}_{-3.4}$ s	$5.12^{+3.19}_{-1.58}$ s	1.89 s	$33.8^{+17.9}_{-11.6}$ s	11.91 s
$^{287}115$	10.74 (9)		32^{+155}_{-14} ms	49 ms	$46.0^{+33.1}_{-19.1}$ ms		207^{+149}_{-85} ms	
$^{283}113$	10.26 (9)	10.60	100^{+490}_{-45} ms	$201.6^{+164.9}_{-84.7}$ms	222^{+172}_{-96} ms	27.1 ms	937^{+719}_{-402} s	116.7 ms
$^{279}111$	10.52(16)	10.45	170^{+810}_{-80} ms	$9.6^{+14.8}_{-5.7}$ ms	$12.4^{+19.9}_{-7.6}$ ms	18.8 ms	$45.3^{+73.1}_{-27.6}$ms	68.8 ms
$^{275}109$	10.48 (9)	10.12	$9.7^{+46}_{-4.4}$ ms	$2.75^{+1.85}_{-1.09}$ms	$4.0^{+2.8}_{-1.6}$ ms	35.2 ms	$13.7^{+9.6}_{-5.6}$ ms	119.5 ms

Most of the theoretical half lives using GLDM are slightly smaller than the experimental data. A reason is perhaps that the rotation of the nuclei is neglected in the present calculations. The additional centrifugal energy contributed to the barrier can reduce the tunnelling probability and increases the half lives. A second reason is that the shell effects and pairing correlation are not explicitly included in the alpha decay barrier, in spite of their global inclusion in the decay energy Q.

The α decay half-lives of the recently produced odd-Z heaviest nuclei calculated with the three approaches and using the experimental Q_α values and without considering the rotational contribution are presented in Table 2. The Q_α values given in Ref.[14] are obtained by extrapolation. Within the GLDM the quantitative agreement with experimental data is visible. The experimental half-lives are reproduced well in six cases ($^{288}115$, $^{284}113$, $^{272}107$, $^{287}115$, $^{283}113$, $^{275}109$) out of nine nuclei along the decay chains of $^{288}115$ and $^{287}115$. Two results ($^{280}111$, $^{276}109$) are underestimated about four to five times possibly because the centrifugal barrier required for the spin-parity conservation could not be taken into account due to non availability of the spin-parities of the decay chain nuclei. On the whole, the results agree well with the experimental data. The results obtained with the DDM3Y interaction agree with the experimental data as well as the GLDM predictions and largely better than the VSS calculations.

One can also find that all calculated half-lives of the $^{279}111$ nucleus are smaller than the experimental ones in table 2. If the contribution of centrifugal barrier is included, the theoretical results will close the experimental data. On the other hand, it is expected that great deviations of a few superheavy nuclei between the data and model may be eliminated by further improvements on the precision of measurements.

3 Conclusions

In conclusion, the half-lives for α-radioactivity have been analyzed in the quasimolecular shape path within a Generalized Liquid Drop Model including the proximity effects between nucleons and the mass and charge asymmetry. The results are in agreement with the experimental data for the alpha decay half-lives and close to the ones derived from the DDM3Y effective interaction. The experimental α decay half lives stand between the GLDM calculations and VSS formulae results.

References

1 Hofmann S, Münzenberg G. Rev. Mod. Phys., 2000, **72**: 733

2 Armbruster P. Eur. Phys. J. A, 2000, **7**: 23

3 Oganessian Yu Ts et al. Phys. Rev. Lett., 1999, **83**: 3154; Eur. Phys. J. A, **5**: 63; Nature, 1999, **400**: 242

4 Blocki J, Randrup J, Swiatecki W J, Tsang C F. Ann. Phys., 1977, **105**: 427

5 Royer G, Remaud B. Nucl. Phys. A, 1985, **444**: 477

6 Royer G, Zbiri K. Nucl. Phys. A, 2002, **697**: 479

7 Royer G, Moustabchir R. Nucl. Phys. A, 2001, **683**: 182

8 Royer G. J. Phys. G, 2000, **26**: 1149

9 Royer G, Gherghescu R A. Nucl. Phys. A, 2002, **699**: 479

10 Myers W D, Swiatecki W J. Nucl. Phys. A, 1996, **601**: 141

11 ZHANG H F, ZUO W, LI J Q, Royer G. Phys. Rev. C, 2006, **74**: 017304

12 Bertsch G, Borysowicz J, McManus H, Love W G. Nucl. Phys. A, 1977, **284**: 399

13 ZHONG X H, LI L, NING P Z. arXiv: nucl-th/0410083 (2003)

14 Audi G, Wapstra A H, Thibaultc. Nucl. Phys. A, 2003, **729**: 337