University of South China
(南华大学)

Systematic study of α decay half-lives based on Gamow–like model with a screened electrostatic barrier

报告人 Jun-Hao Cheng (程俊皓)
导师 Xiao-Hua LI (李小华)

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cjh452002@163.com

Outline

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2. The Gamow--like model
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The theoretical models of α decay

α decay, as an important tool to investigate superheavy nuclei (SHN), provides abundant information about the nuclear structure and stability of SHN。 Within Gamow’ s theory, the α decay process is described as a preformed α particle penetrating the Coulomb barrier.

$$T_{1/2} = \frac{\hbar \ln 2}{\Gamma} = \frac{\ln 2}{\lambda}$$

$$\lambda = P_\alpha \nu P$$

P_α denotes α preformation factors,
ν is the assault frequency of α particle,
P denote the semiclassical Wentzel-Kramers-Brillouin (WKB) barrier penetrate probability

张鸿飞老师课题组

GLDM

Introduction

Representative model:
Generalized Liquid Drop Model
Representative work:
H. F. Zhang and G. Royer, Phys. Rev. C 77, 054318 (2008) ……

任忠洲老师课题组

CM&DDCM

Introduction

Representative model:
The Cluster Model, Density-Dependent Cluster Model
Representative work:
C. Xu and Z. Ren, Nucl. Phys. A 760, 303 (2005)
C. Xu and Z. Ren, Phys. Rev. C 73, 041301 (2006)……

孟杰老师课题组

RMF

Introduction

Representative model:
The Relativistic Mean Field Model
Representative work:
W. Long, J. Meng, and S.-G. Zhou, Phys. Rev. C 65, 047306 (2002) ……

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CPPM

Introduction

Representative model:
The Coulomb and Proximity Potential Model
Representative work:
C. L. Guo, G. L. Zhang and X. Y. Le, Nucl. Phys. A 897, 54 (2013) ……

王艳召老师课题组

ELDM

Introduction

Representative model:
The Effective Liquid Drop Model
Representative work:
Y. Z. Wang, J. P. Cui, Y. L. Zhang, S. Zhang, and J. Z. Gu, Phys. Rev. C 95, 014302 (2017) ……

左维老师课题组

UFM

Introduction

Representative model:
The Unified Fission Model
Representative work:
J. Dong, W. Zuo, J. Gu, Y. Wang, and B. Peng, Phys. Rev. C 81, 064309 (2010) ……

The Gamow--like model

IOP Publishing PHYSICA SCRIPTA
Phys. Scr. T154 (2013) 014029 (5pp) doi:10.1088/0031-8949/2013/T154/014029

Half-lives for α and cluster radioactivity in a simple model

A Zdeb, M Warda and K Pomorski

Katedra Fizyki Teoretycznej, Uniwersytet Marii Curie-Skłodowskiej, Lublin, Poland

E-mail: pomorski@kft.umcs.lublin.pl

PHYSICAL REVIEW C **87**, 024308 (2013)

Half-lives for α and cluster radioactivity within a Gamow-like model

A. Zdeb,* M. Warda, and K. Pomorski
Katedra Fizyki Teoretycznej, Uniwersytet Marii Curie-Skłodowskiej, Lublin, Poland
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A simple phenomenological model based on the Gamow theory for the evaluation of half-lives for α and cluster radioactivity is proposed. The model contains only one adjustable parameter: the nuclear radius constant, common for both kind of decays and an additional hindrance factor to the lifetimes which gives the effect of an odd particle. A good agreement with the experimental data for nuclei with $Z \geqslant 84$ and $N \geqslant 104$ is achieved.

- **Zedb et al.** show that using only one adjustable parameter, the radius constant, it is possible to reproduce with a good accuracy all existing data for decays of even-even nuclei.
- **Zedb et al.** describes the decay of odd systems by introducing hindrance factor *h*.

$$T_{1/2} = \frac{\ln 2}{\lambda} 10^h$$

- ***References :***

[1] Zdeb A, Warda M and Pomorski K ,Phys. Rev. C 87, 024308 (2013).

[2] Zdeb A, Warda M and Pomorski K, Phys. Scr. T 154, 014029 (2013).

The theoretical framework of the Gamow-like model :

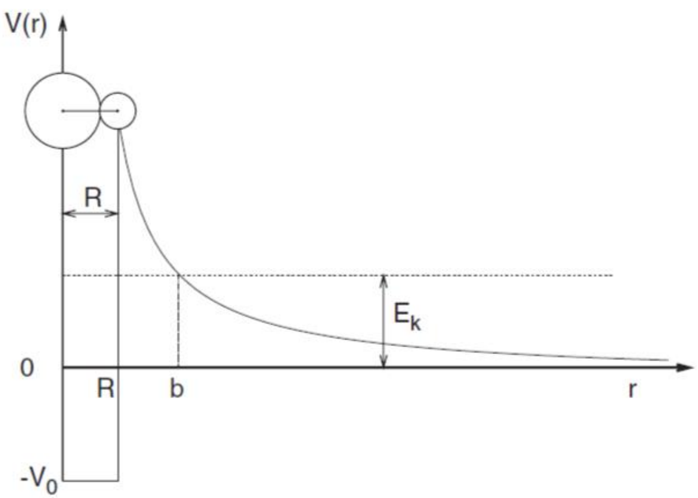

FIG. 1. Schematic plot of the potential energy as a function of the distance between the centers of the decaying nuclei.

The potential energy $V(r)$ is given by:

$$V(r) = \begin{cases} -V_0 & 0 \le r \le R \\ \dfrac{Z_d Z_\alpha e^2}{r} & r > R \end{cases}$$

The square well radius R:

$$R = r_0(\mathrm{Ad}^{1/3} + \mathrm{A}_\alpha{}^{1/3})$$

The outer turning point b is determined by the condition $V(r) = Ek$

$$b = \frac{Z_d Z_\alpha e^2}{E_k}$$

The theoretical framework of the Gamow-like model :

The α decay penetration probability :

$$P = \exp\left[-\frac{2}{\hbar}\int_{R}^{b}\sqrt{2\mu(V(r) - E_k)}\,dr\right]$$

$$\Rightarrow \quad P=\exp\left\{-\frac{2}{\hbar}\sqrt{2\mu b Z_1 Z_2 e^2}\left[\arccos\sqrt{\frac{R}{b}} - \sqrt{\frac{R}{b} - \left(\frac{R}{b}\right)^2}\right]\right\}$$

The assault frequency of α decay :

$$\nu = \frac{1}{2R}\sqrt{2Ek/\mu}$$

Our works

"In the present work we systematically study α decay half-lives of Z > 51 nuclei using the modified Gamow-like model which includes the effects of the centrifugal potential and **electrostatic shielding**."

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Systematic study of α decay half-lives based on Gamow–like model with a screened electrostatic barrier

Jun-Hao Cheng [a], Jiu-Long Chen [a], Jun-Gang Deng [a], Xi-Jun Wu [b], Xiao-Hua Li [a,c,d,*], Peng-Cheng Chu [e]

By considering the effect of non-zero electrostatic screening , we introduce a screened electrostatic barrier *i.e.* the **Hulthen potential** to compare with the Coulomb potential.

The Coulomb potential

$$V_C(r) = \frac{e^2 Z_d Z_\alpha}{\mathrm{r}}$$

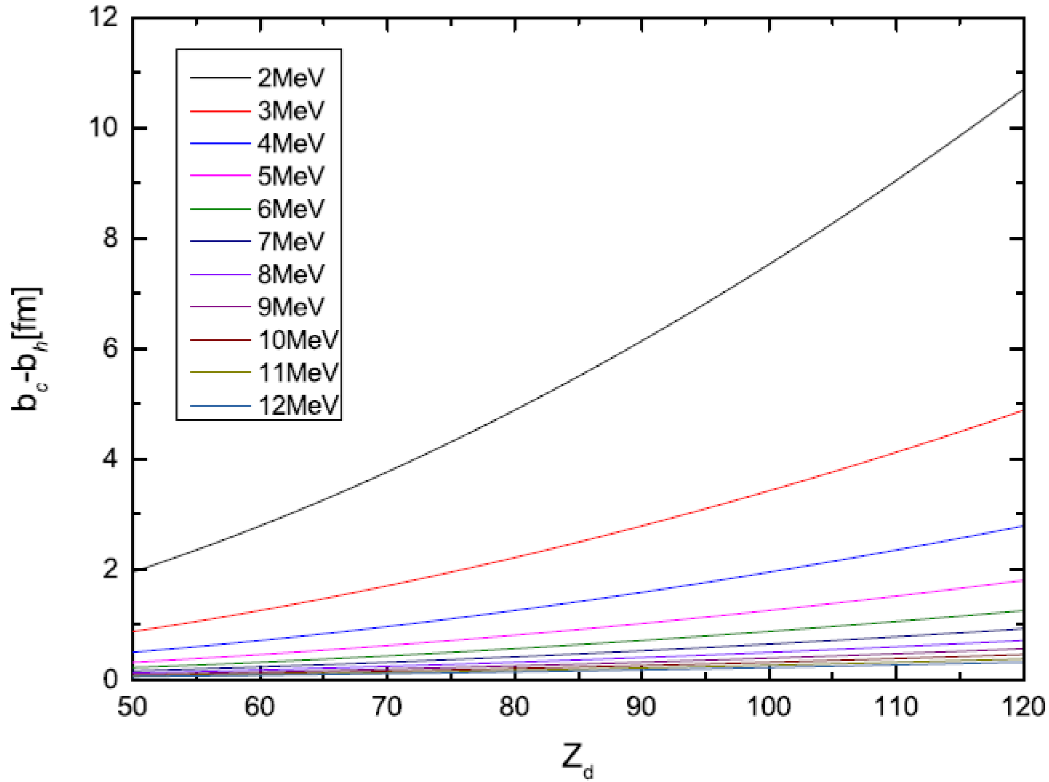
The Hulthen potential

$$V_H(r) = \frac{a e^2 Z_d Z_\alpha}{\exp(ar) - 1},$$

- For the superposition of the **involved charges**, movement of the proton which generates a **magnetic field** and the **inhomogeneous charge distribution** of the nucleus, the α-daughter nucleus electrostatic potential (**Hulthen potential**) behaves as a Coulomb potential at short distance and drop exponentially at large distance.

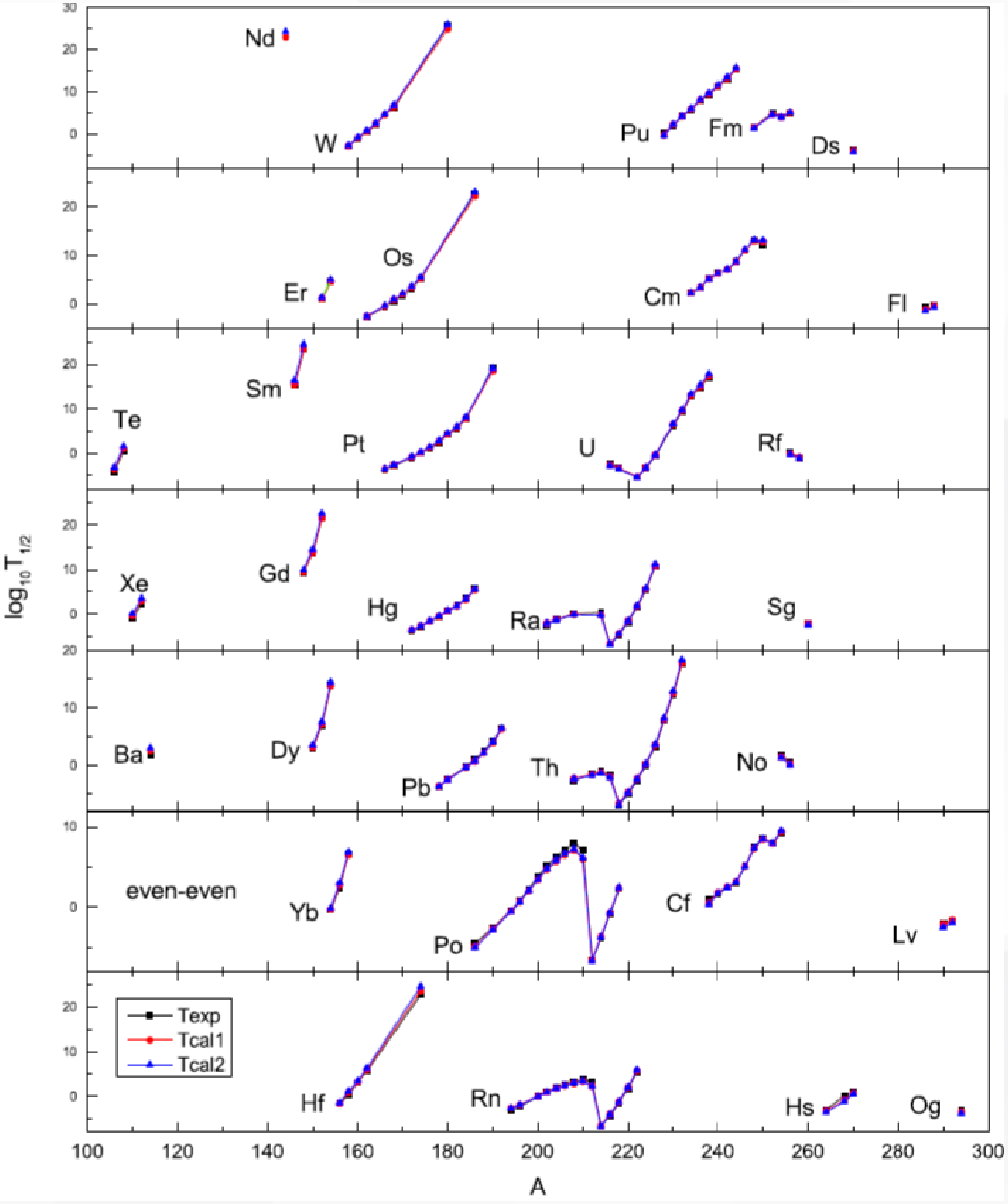
Taylor expansion:

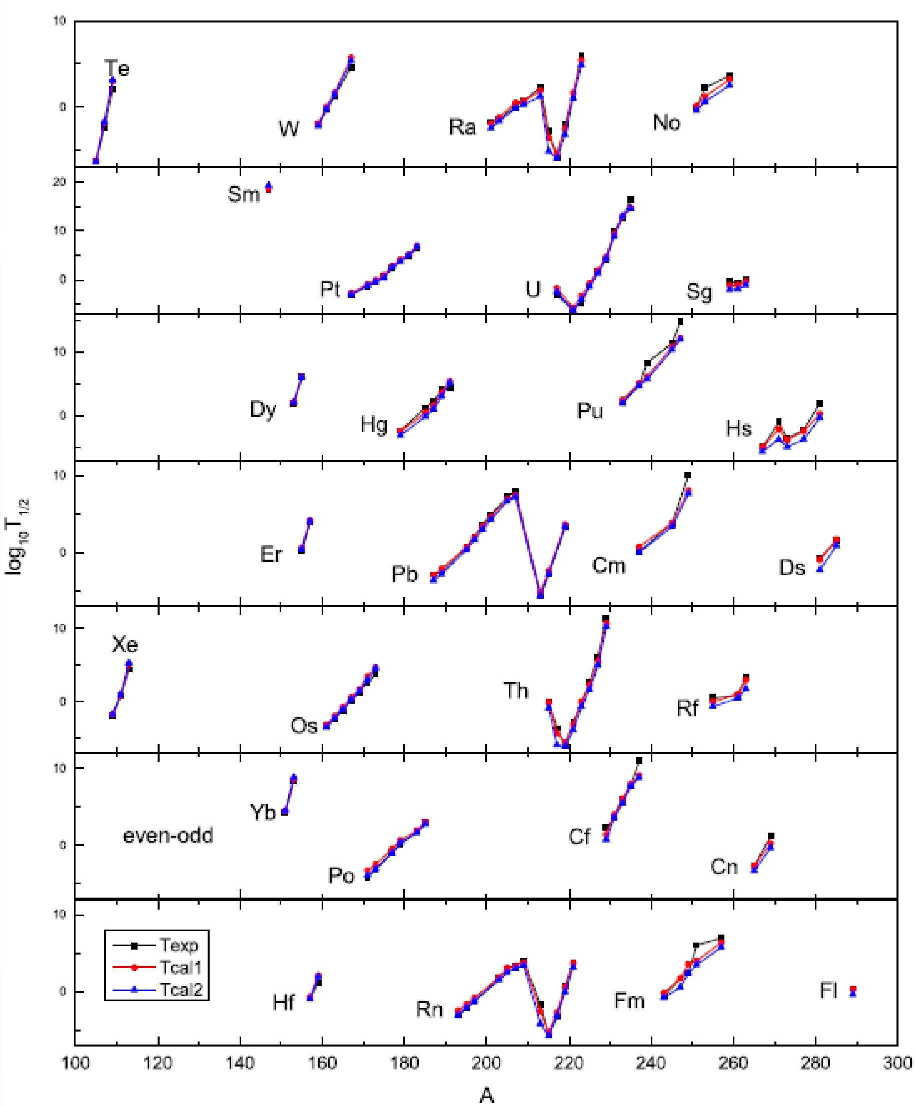
$$\lim_{r\to 0}\frac{ar}{\exp(ar)-1}=1 \Longrightarrow \lim_{r\to 0}\frac{ae^2 Z_d Z_\alpha}{\exp(ar)-1}=\frac{e^2 Z_d Z_\alpha}{r}$$

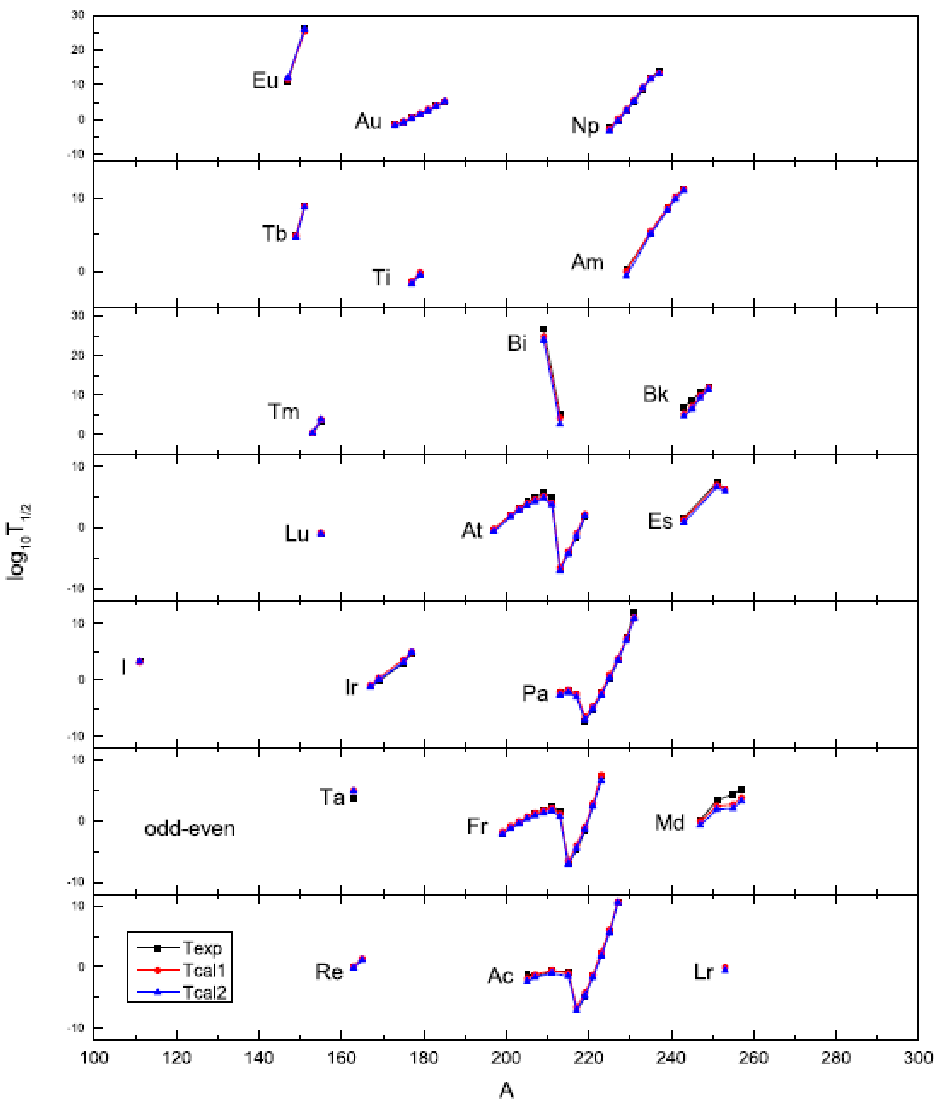


- The difference between b_c and b_h obtained by V(r) = E_k.
- From this figure, we can find that the smaller decay energy and larger proton number of the daughter nucleus are, the greater difference in the b value between the pure Coulomb and the Hulthen potential be.

- The calculated results for even-even nuclei can reproduce the experimental data well.
- Tcal1 and Tcal2 is the logarithmic form of the α decay half-life calculated by our work and Gamow-like model, respectively.

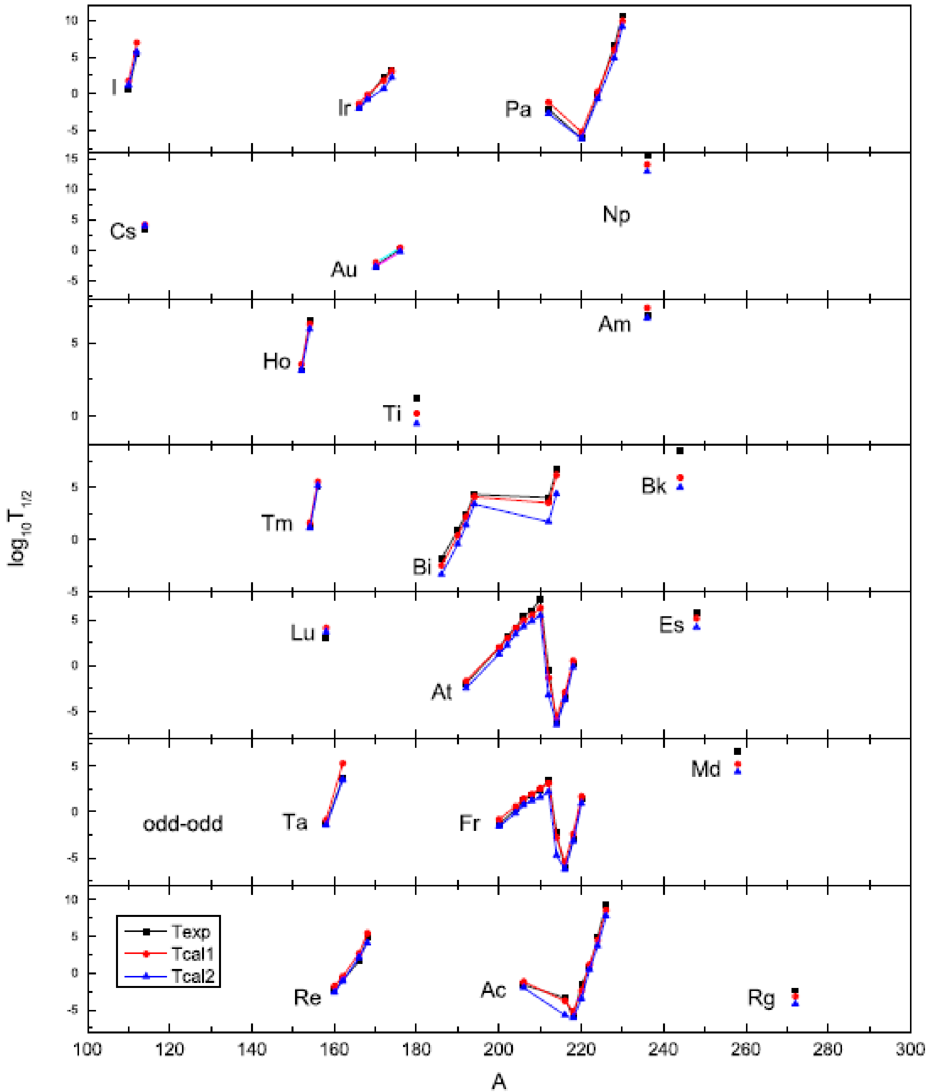






For **even-Z, odd-N** nuclei

For **odd-Z, even-N** nuclei



$\pi_z - \pi_n$	n	h	σ_1	σ_2
e-e	169	–	0.348	0.487
e-o	132	0.3455	0.681	0.967
o-e	94	0.3455	0.598	0.789
o-o	66	0.691	0.748	1.235

Comparison with Gamow-like model shows that the results have a certain improvement.

For **odd-Z, odd-N** nuclei

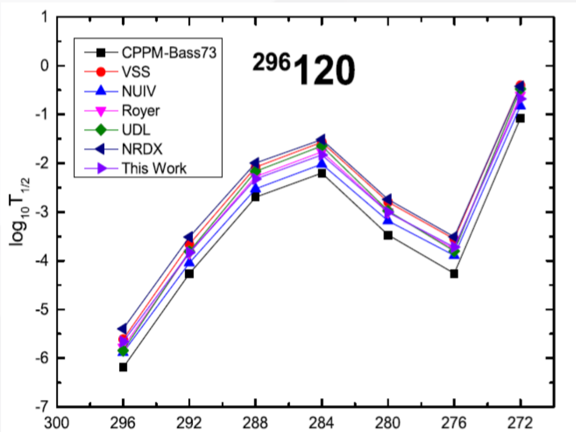
APPLICATION

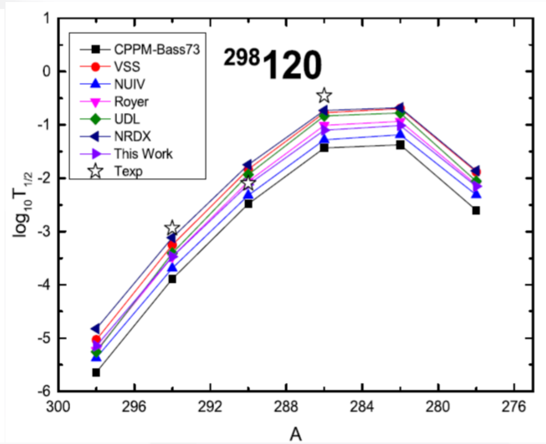
We use our model to predict the α decay half-lives of nuclei **Z=120** i.e. $^{296}120$, $^{298}120$, $^{300}120$, $^{302}120$, $^{304}120$, $^{306}120$ as well as $^{308}120$ and some un-synthesized nuclei on their α decay chains.

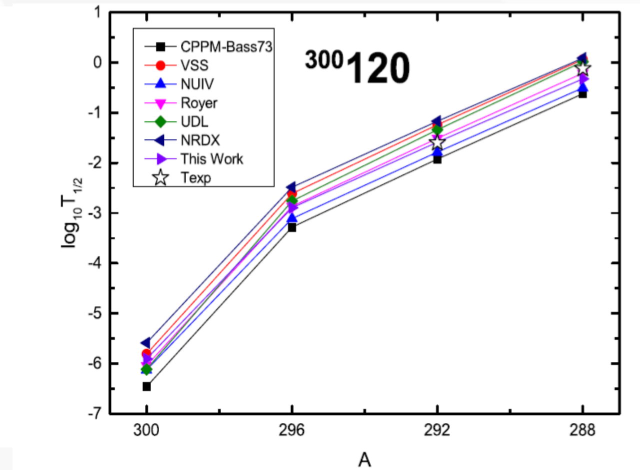
Meanwhile Sobiczewski discovered that the calculation taking α decay energy from **WS3+** can best reproduce experimental α decay half-life.

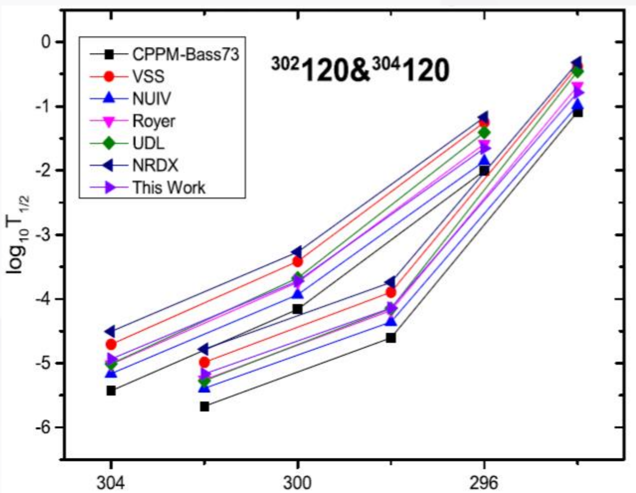
COMPARE

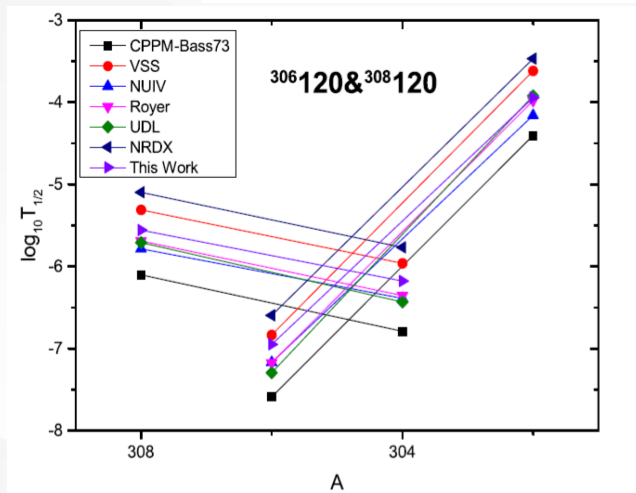
We also systematically calculate the α decay half-lives of even-even nuclei of proton numbers Z=120 and nuclei on their α decay chain using Coulomb potential and Proximity potential model with proximity potential Bass73 formalism (**CPPM-Bass73**) , the Viola-Seaborg-Sobiczewski (**VSS**) empirical formula, the Universal (**UNIV**) curve , **Royer formula**, the Universal decay law (**UDL**) and the Ni-Ren-Dong-Xu (**NRDX**) empirical formula, respectively.











The different cases of α decay half-lives calculated by different theories.

Δ between α decay half-lives of calculations and experimental data of different theories.

A of nucleus	$\Delta_{CPPM-bass73}$	Δ_{VSS}	Δ_{UNIV}	Δ_{Royer}	Δ_{UDL}	Δ_{NRDX}	$\Delta_{This-work}$
298	0.817	0.299	0.656	0.443	0.360	0.276	0.482
300	0.419	0.286	0.299	0.091	0.212	0.342	0.142

Summary

Conclusions:

I. We modify the Gamow-like model by considering the effects of screened electrostatic for Coulomb potential and the centrifugal potential and use this model systematically to study α decay half-lives for Z>51 nuclei.

II. We extend this model to the superheavy nuclei, and predict the half-lives of seven even-even nuclei with a proton number Z=120 and some un-synthesized nuclei on their α decay chains.

THANKS