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Alpha decay properties of heavy and superheavy elements

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Abstract. Analysing accurately the lifetimes of α-decay chains is an important tool to detect and study the properties of superheavy nuclei. ^{48}Ca is used in the synthesis of superheavy nuclei $Z = 106-118$ at Dubna. The experimental work of ^{48}Ca projectiles at Dubna has given an opportunity to study the superheavy element (SHE). Here, the α-decay properties for $Z = 106$–118 are evaluated using our CYE model and are compared with the available experimental and theoretical values.

Keywords. Superheavy element; alpha decay; half-lives.

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1. Introduction

In recent years, remarkable progress has been made in the field of superheavy elements (SHEs). Both theoretical and experimental methods have been applied in the investigation of superheavy atomic nuclei, that is, the heavy nuclei which exist or are expected to exist only due to shell effects. Much progress has been made in investigating the decay properties of very heavy atomic nuclei. Elements with $Z = 107-112$ have been synthesized at GSI, Darmstadt [1,2] and their results gave a pronounced enlargement of lifetimes for $Z = 106 - 118$ nuclei. Based on this, here we apply our well-known cubic plus Yukawa plus exponential (CYE) model which is successful in predicting the decay properties of transactinide elements by two-sphere approximation [3,4] and also the properties of trans-tin elements including deformation effects [5] for studying superheavy elements.

2. Description of the CYE model

In order to study the properties of SHEs a realistic model called cubic plus Yukawa plus exponential (CYE) model was used. Here, the zero-point vibration energy is explicitly included without violating the conservation of energy and the inertial mass coefficient depending on the centre of mass distance. It has a cubic potential for the overlapping region which is smoothly connected by a Yukawa plus exponential potential for the region after separation. Then the potential as a function of r (which is the centre of mass distance of the two spherical fragments) for the postscission region is given by

$$V(r) = \frac{Z_1 Z_2 e^2}{r} + V_n(r) - Q, \qquad r \geq r_t. \tag{1}$$

For calculating the zero-point vibration energy E_v,

$$E_\mathrm{v} = \frac{\pi\hbar}{2} \frac{[2Q/\mu]^{1/2}}{(C_1 + C_2)}, \tag{2}$$

Table 1. Comparison of half-lives calculated using CYE model with WKB barrier penetration probability [11] and also with the experimental values [6–9].

		$T_{1/2}$			
Parent ^{A}Z	$Q_{\mathrm{Exp.}}$ (MeV)	This work CYEM model	WKB [11]	Exp.	Ref. (Exp.)
$^{271}106$	8.67 [9]	2.83 min	$0.86^{+.71}_{-0.39}$ min	$1.9^{+2.4}_{-0.6}$ min	[6]
$^{266}107$	9.26 [13]	6.166 s	$5.73^{+1.82}_{-1.38}$ s	2.47 s	[9]
$^{272}107$	9.15 [7]	10.715 s	$10.1^{+5.4}_{-3.4}$ s	$9.8^{+11.7}_{-3.5}$ s	[7]
$^{275}108$	9.44 [7]	2.884 s	$1.09^{+0.61}_{-0.35}$ s	$0.19^{+0.22}_{-0.07}$ s	[6]
$^{270}109$	10.23 [8]	42.6 ms	$52.05^{+27.02}_{-17.68}$ ms	7.16 ms	[9]
$^{275}109$	10.48 [10]	7.413 ms	$2.75^{+1.85}_{-1.09}$ ms	$9.7^{+46}_{-4.4}$ ms	[7]
$^{276}109$	9.85 [7]	0.398 s	$0.45^{+0.23}_{-0.14}$ s	$0.72^{+0.87}_{-0.25}$ s	[7]
$^{279}110$	9.84 [7]	0.9120 s	$0.40^{+0.18}_{-0.13}$ s	$0.20^{+0.05}_{-0.04}$ s	[6]
$^{274}111$	11.36 [12]	0.25 ms	$0.39^{+18}_{-0.12}$ms	9.26 ms	[9]
$^{279}111$	10.52 [12]	26.3 ms	$9.6^{+14.8}_{-5.7}$ ms	107^{+810}_{-80} ms	[7]
$^{280}111$	9.87 [7]	1.698 s	$1.9^{+0.9}_{-0.6}$ s	$3.6^{+4.3}_{-1.3}$ s	[7]
$^{283}112$	9.67 [7]	14.45 s	$5.9^{+2.9}_{-2.0}$ s	$3.8^{+1.2}_{-0.7}$ s	[6]
$^{285}112$	9.29 [7]	213.79 s	75^{+41}_{-26} s	34^{+17}_{-9} s	[8]
$^{278}113$	11.90 [13]	0.055 ms	101^{+27}_{-18} μs	344 μs	[9]
$^{283}113$	10.26 [10]	630 ms	$201.6^{+164.9}_{-84.7}$ ms	100^{+490}_{-45} ms	[7]
$^{284}113$	10.15 [7]	1.258 s	$1.55^{+0.72}_{-0.48}$ s	$0.48^{+0.58}_{-0.17}$ s	[7]
$^{286}114$	10.33 [7]	0.8317 s	$0.16^{+0.07}_{-0.05}$ s	$0.13^{+0.04}_{-0.02}$ s	[6]
$^{287}114$	10.16 [7]	2.455 s	$1.13^{+0.52}_{-0.35}$ s	$0.48^{+0.16}_{-0.09}$ s	[6]
$^{288}114$	10.09 [8]	3.715 s	$0.67^{+0.37}_{-0.27}$ s	$0.8^{+0.32}_{-0.18}$ s	[8]
$^{289}114$	9.96 [7]	8.709 s	$3.8^{+1.8}_{-1.2}$ s	$2.7^{+1.4}_{-0.7}$ s	[8]
$^{287}115$	10.74 [10]	134.9 ms	$51.7^{+35.8}_{-22.2}$ ms	32^{+155}_{-14} ms	[7]
$^{288}115$	10.61 [7]	295 ms	$410.5^{+179.4}_{-122.7}$ ms	87^{+105}_{-30} ms	[7]
$^{290}116$	11.00 [9]	56 ms	$13.4^{+.7.7}_{-5.2}$ ms	$7.1^{+3.2}_{-1.7}$ ms	[6]
$^{291}116$	10.89 [8]	104.7 ms	$60.4^{+.30.2}_{-20.1}$ ms	18^{+22}_{-6} ms	[6]
$^{292}116$	10.80 [8]	173.8 ms	$39^{+.20}_{-13}$ ms	18^{+16}_{-6} ms	[8]
$^{293}116$	10.67 [7]	38 ms	206^{+90}_{-61} ms	53^{+62}_{-19} ms	[8]
$^{294}118$	11.81 [7]	2.188 ms	$0.66^{+0.23}_{-0.18}$ ms	$0.89^{+1.07}_{-0.31}$ ms	[6]

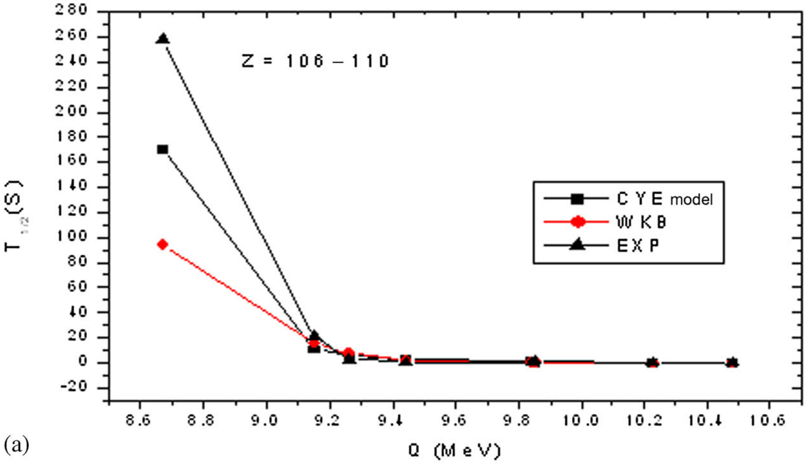
where C_1 and C_2 are the central radii of the fragments and is given by

$$C_i = 1.18\, A_i^{1/3} - 0.48, \qquad i = 1, 2$$

and

$$\mu = \frac{mA_1A_2}{A},$$

where μ is the reduced mass of the system and m is the mass of the nucleon.



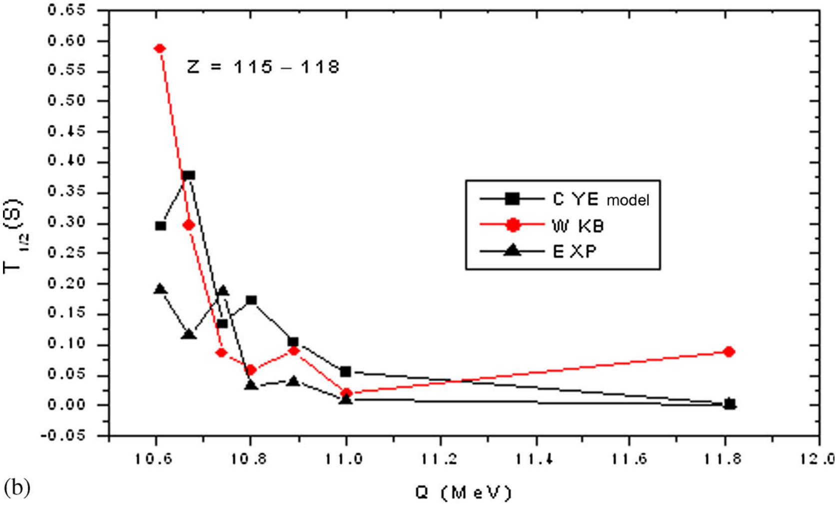


Figure 1. (**a**) Comparison of α-decay half-life using CYE model with WKB and experimental values for $Z = 106$–110. (**b**) Comparison of α-decay half-life using CYE model with WKB and experimental values for $Z = 115$–118.

The half-life time of the system is calculated using the formula

$$T = \frac{1.433 \times 10^{-21}(1+\exp k)}{E_{\mathrm{v}}}, \tag{3}$$

where

$$k = \frac{2}{\hbar}\left\{\int_{r_a}^{r_t} [2\boldsymbol{B_r}\,(\boldsymbol{r})\,\boldsymbol{V}\,(\boldsymbol{r})]^{1/2}\mathrm{d}\boldsymbol{r} + \int_{r_t}^{r_b} [2\boldsymbol{B_r}\boldsymbol{V}\,(\boldsymbol{r})]^{1/2}\right\}\mathrm{d}\boldsymbol{r}. \tag{4}$$

Here r_a and r_b are the two appropriate zeros of the integrand.

3. Alpha decay half-lives of heavy and superheavy elements

In this work, using CYE model we have tried to study the α-decay half-life for trans-actinide heavy and superheavy elements with atomic number ranging from $Z = 106$ to 118.

In table 1, the α-decay half-life values are given for $Z = 106$–118 using CYE model and are compared with the WKB barrier penetration probability [11] and also with the available experimental results [6–9]. For the half-life calculations, the experimental Q values are taken from [7–10,12,13] and are also shown in table 1.

From figures 1a and 1b, it is seen that the calculated half-life values are closer to the available experimental and theoretical results.

4. Summary and conclusion

In the study of SHE, the theoretical estimate of α-decay half-lives is very useful for the experimental analysis. Here, we have computed the theoretical estimates for the α-decay half-lives of SHEs with $Z = 106 - 118$ by CYE model using experimental Q values which are presented in this paper. The results are in good agreement over a wide range of experimental data and also with the available theoretical calculations.

References

[1] S Hofmann *et al*, *Nucl. Phys. A* **734**, 93 (2004)
[2] H Hofmann and G Munzenberg, *Rev. Mod. Phys.* **72**, 733 (2000)
[3] G Shanmugam and B Kamalakaran, *Phys. Rev. C* **38**, 1377 (1988)
[4] G Shanmugam, G M Carmel Vigila Bai and B Kamalakaran, *Phys. Rev. C* **51**, 2616 (1995)
[5] G M Carmel Vigila Bai, *A systematic study of cluster radioactivity in trans-tin region,* Ph.D. Thesis (Manonmaniam Sundaranar University, Tirunelveli, 1997)
[6] Yu Ts Oganessian *et al*, *Phys. Rev. C* **74**, 044602 (2006)
[7] Yu Ts Oganessian *et al*, *Phys. Rev. C* **69**, 021601(R) (2004); *Phys. Rev. C* **72**, 034611 (2005)
[8] Yu Ts Oganessian *et al*, *Phys. Rev. C* **70**, 064609 (2004); *Phys. Rev. C* **71**, 029902(E) (2005)
[9] K Morita *et al*, *J. Phys. Soc. Jpn.* **73**, 25939 (2004)
[10] K Morita *et al*, *Nucl. Phys. A* **734**, 101 (2004)
[11] C Samanta, P Roy Chowdhury and D N Basu, *Nucl. Phys. A* **789**, 142 (2007)
[12] I Muntian, S Hofmann, Z Patyk and A Sobiczewski, *Acta Phys. Pol. B* **32**, 691 (2001)
[13] D Ackermann, *Nucl. Phys. A* **787**, 353 (2007)