Alpha decay half-lives of Super Heavy Nuclei with Z=115-125

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I. Introduction

Studying and identifying the alpha decay characteristics of superheavy elements is crucial, as it offers deep insights into nuclear binding energy, internal structure, and decay behavior. Among the various decay modes, alpha emission stands out as a predominant process in these heavy nuclei. The phenomenon was first discovered by Rutherford [1,2] over a hundred years ago. In 1928, George Gamow [3] provided a theoretical explanation, linking alpha decay to quantum tunneling—where alpha particles escape the nucleus by penetrating the potential barrier. Around the same time, Condon and Gurney independently described the same process using wave mechanics. Their model suggested that alpha particles are already formed inside the nucleus and gradually escape by overcoming the Coulomb barrier, which arises due to the repulsive force between the alpha particle and the protons of the daughter nucleus.

II. Universal Decay Law (UDL)

The quest for a unified description of α-decay phenomena beyond the classical Geiger-Nuttall law has led to concerted efforts to formulate a universal scaling law capable of characterizing all forms of charged-particle emission. A significant advancement in this direction was achieved by Qi et al., who derived a universal decay law (UDL) [4] valid for both α-particle and cluster radioactivity. This formulation provides a model-independent framework, facilitating the systematic prediction of new decay modes and the investigation of decay systematics across the nuclear landscape.

The theoretical foundation of the UDL is rooted in the R-matrix theory of nuclear reactions, which provides a robust description of resonance processes. For the emission of a charged cluster, the decay width Γ_c can be expressed within this framework. Thomas derived the half-life for cluster decay by evaluating the residues of the S matrix, yielding the relation

$$T_{1/2} = \frac{\hbar \ln 2}{\Gamma_c} \approx \frac{\ln 2}{\nu} \left| \frac{H_\ell^+(\chi,\rho)}{RF_c(R)} \right|^2$$

where ν denotes the asymptotic velocity of the emitted cluster carrying angular momentum ℓ. The distance R represents the separation between the cluster and daughter nucleus at which the nuclear interaction becomes negligible. The Coulomb-Hankel function, H_ℓ^+, is evaluated with the standard arguments: the dimensionless distance $\rho=\mu\nu R/\hbar$ and the Coulomb parameter $\chi = 2Z_cZ_de^2/\hbar\nu$, with μ being the reduced mass of the system. The cluster formation amplitude, $F_c(R)$, is a critical quantity representing the overlap of the parent nuclear wavefunction with the antisymmetric zed tensor product of the daughter and cluster wavefunctions at the separation surface.

Through a simplification of the R-matrix expression, Qi et al. recast the half-life into a linear form. This reformulation allows the logarithmic decay half-life, offset by a term encompassing cluster formation effects, to be expressed as a linear function of a variable related to the Coulomb penetration. The resultant Universal Decay Law is given in logarithmic form as

$$\log_{10}(T_{1/2}) = aZ_cZ_d\sqrt{\frac{A}{Q_c}} + b\sqrt{AZ_cZ_d\left(A_d^{1/3} + A_c^{1/3}\right)} + c$$

$$- a\chi' + b\rho' + c$$

The coefficients *a*, *b*, and *c* are universal constants determined from a fit to experimental α and cluster decay half-lives, yielding the values *a* = 0.4314, *b* = –0.4087, and *c* = –25.7725.

Q_c is the Q-value of the nuclear decay and the term $A = A_dA_c/(A_d + A_c)$. Where A_d,

A_c represents the masses of the daughter and cluster nuclei respectively.

III. Results and discussion

Alpha decay of superheavy nuclei with atomic numbers Z = 115–125 has been systematically investigated within the framework of the Universal Decay Law (UDL). This study aims to elucidate the decay properties of these nuclides by combining a robust theoretical model with the latest mass predictions.

The α-decay energy (Q-value) for each transition was calculated according to

$$Q = M_p - (M_\alpha + M_d)$$

Where M_p, M_d, M_α denote the masses of the parent nucleus, daughter nucleus, and α-particle, respectively. All nuclear masses were adopted from the WS3 + RBF [5] mass model to ensure consistency and predictive accuracy. Eleven isotopic chains were examined: A = 289–339 for Z = 115, 292–342 for Z = 116, 291–341 for Z = 117, 292–342 for Z = 118, 293–343 for Z = 119, 294–344 for Z = 120, 295–345 for Z = 121, 296–346 for Z = 122, 297–347 for Z = 123, 298–348 for Z = 124, and 299–349 for Z = 125. For each isotope within these ranges, the logarithm of the half-life ($\log_{10}T_{1/2}$) was evaluated, and the minimum values obtained are compiled in Table.

Parent Nuclei	Daughter Nuclei	Neutron Number of daughter with Minimum $\log_{10}T_{1/2}$	Minimum $\log_{10}T_{1/2}$ (s) (UDL)
$^{301}115$	$^{297}113$	184	-4.516
$^{302}116$	$^{298}114$	184	-7.375
$^{303}117$	$^{299}115$	184	-8.282
$^{304}118$	$^{300}116$	184	-8.674
$^{305}119$	$^{301}117$	184	-8.967
$^{306}120$	$^{302}118$	184	-9.360
$^{307}121$	$^{303}119$	184	-10.062
$^{308}122$	$^{304}120$	184	-10.814
$^{309}123$	$^{305}121$	184	-11.038
$^{310}124$	$^{306}122$	184	-11.102
$^{311}125$	$^{307}123$	183	-11.560

Graphs were plotted between the logarithmic half-lives and the neutron number of the daughter nuclei. For elements with atomic numbers Z = 115 to 124, the minimum half-life occurs at neutron number 184, whereas for Z = 125, the minimum is observed at neutron number 183.

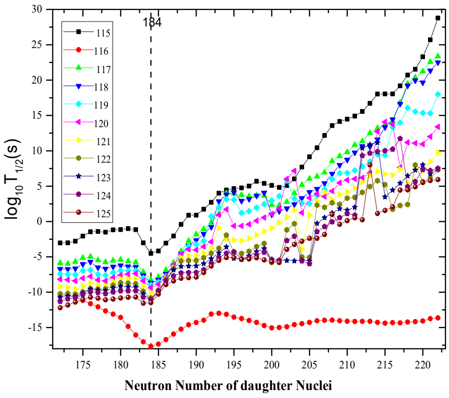

Fig.1 $\log_{10}T_{1/2}$ Vs Neutron number of daughter nuclei

IV. Conclusion

For elements with Z = 115 to Z = 124, the minimum half-life consistently occurs at neutron number N = 184, aligning with the predicted magic number associated with spherical shell closure in superheavy nuclei. Notably, for Z = 125, the minimum shifts slightly to N = 183, suggesting a subtle evolution in shell structure or pairing effects at the upper edge of the studied region.

These observations reinforce the significance of the N=184 shell gap in stabilizing superheavy systems and provide valuable insight into the decay dynamics near the predicted island of stability.

References

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