Alpha decay chains of $^{291-294}$Ts

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Introduction

The alpha decay chain of superheavy nuclei not only reveals the intricate processes governing nuclear stability but also highlights the potential for discovering new isotopes through advanced experimental techniques. The study of isotopes with extreme neutron-to-proton ratios could shed light on the limits of nuclear stability and the processes that govern nucleosynthesis in stellar environments. In the present work, we have studied the alpha decay chains of the isotopes of the superheavy nuclei, tennessine (Ts) with Z = 117, using the Effective Liquid Drop model (ELDM).

Effective Liquid Drop Model

ELDM provides a coherent paradigm to explain α and cluster decay[1]. The barrier penetrability factor P is calculated using WKB approximation

$$P = exp\{-\frac{2}{\hbar}\int_{\zeta_1}^{\zeta_2}\sqrt{2\mu(V-Q)}d\zeta\} \quad (1)$$

Here total potential (V) includes Coulomb, surface and centrifugal terms[2]. The inertia coefficient, μ, is calculated using the effective inertia approximation. The half-life for the decay is obtained as

$$T_{1/2} = \frac{ln2}{\lambda} \quad (2)$$

λ represents the decay constant, which is determined using

$$\lambda = \lambda_0 P \quad (3)$$

where λ_0 is the assault frequency ($\lambda_0 \approx 10^{22}s$).

In addition to ELDM, two semi-empirical formulae were used. The logarithmic half-life of a nucleus undergoing cluster decay (here α) is given by Universal Decay Law (UDL)[3] as

$$log_{10}T_{1/2} = aZ_cZ_d\sqrt{\frac{A}{Q}} + b\sqrt{AZ_cZ_d(A_d^{1/3}+A_c^{1/3})} + c \quad (4)$$

where A, A_c and A_d are the reduced mass, the mass of the cluster, and the mass of the daughter respectively. Here the constants are $a = 0.4314, b = -0.4087$ and $c = -27.7725$.

The analytical formula for $\alpha-$decay half-lives which was developed by Royer is given by,

$$log_{10}T_{1/2} = a + bA^{1/6}\sqrt{Z} + \frac{cZ}{\sqrt{Q}} \quad (5)$$

where A and Z represent the mass number and atomic number of the parent nuclei. The constant a, b and c are given in [4]

The half-life of spontaneous fission is determined using the semi-empirical formula of Xu[5].

$$T_{1/2} = exp\{2\pi[C_0 + C_1A + C_2Z^2 + C_3Z^4 + C_4(N-Z)^2 - (0.13323Z^2/A^{1/3} - 11.6)]\} \quad (6)$$

The constants are $C_0 = -195.09227, C_1 = 3.10156, C_2 = -0.04386, C_3 = 1.4030 * 10^{-6}$ and $C_4 = -0.003199$

Result and Discussion

The alpha decay chains of Ts isotopes with A = 291 to 294 are analysed using ELDM. A decay mode is favourable only when the Q-value is positive. Q-value is evaluated using the formula,

$$Q = \Delta M_p - (\Delta M_d + \Delta M_\alpha) \quad (7)$$

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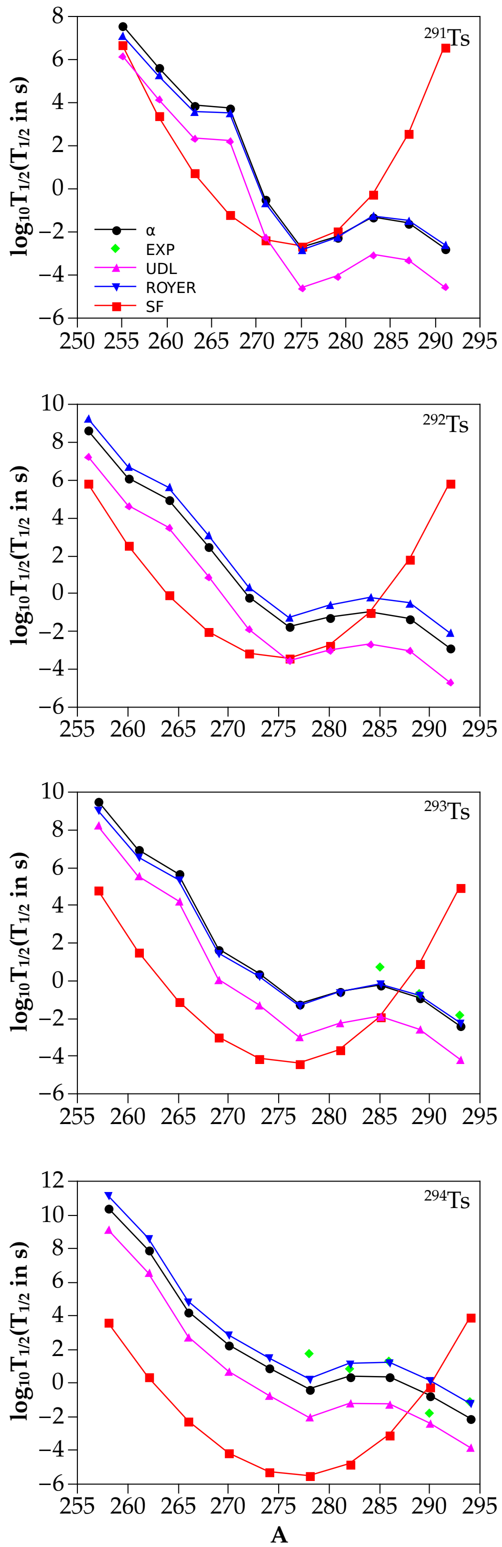

FIG. 1: Comparison of alpha decay chains and spontaneous fission of $^{291-294}$Ts isotopes

where ΔM_p, ΔM_d, and ΔM_α are the mass excess of the parent, the daughter, and the alpha particle, respectively. The mass excess of the isotopes is taken from AME 2020 [6].

Fig. 1 shows the alpha decay chains of the isotopes under study. Spontaneous fission half-lives are also displayed to identify the end of the alpha decay chain. We have also shown the half-lives of the experimentally synthesised isotopes ^{293}Ts and ^{294}Ts. The alpha decay chains computed using ELDM are compared with semi-empirical formulae UDL and Royers formula. The UDL values underestimate the other two predictions. All the theoretical values follow a similar trend in the prediction of the decay chains. The predicted outcomes are consistent with the CPPM results[7]. Here we can see that all the isotopes endure fission, which results in alpha emission leading to the synthesis of new isotopes. The comparison of alpha decay half-lives and spontaneous fission half-lives predicts the existence of 5α chains for ^{291}Ts, 3α chains for ^{292}Ts, and 2α chains for ^{293,294}Ts. The alpha decay chains of ^{291}Ts gives rise to ^{287}Mc, ^{283}Nh, ^{279}Rg, and ^{275}Mt isotopes. Likewise for other isotopes of tennessine as well.

Examining these decay chains may also enhance the quest for novel isotopes and their attributes, potentially identifying previously unrecognized elements or isotopes with unusual features.

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