Alpha decay chains of ^{275,276}Mt

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Introduction

Superheavy nuclei (SHN) and their decay studies have received much attention in the past few decades. SHN are mainly produced using hot fusion reaction and cold fusion reaction. The decay studies of SHN are important since it is the only way to identify the newly formed SHN. Alpha decay and spontaneous fission (SF) are the main decay modes of SHN.

In the present paper we have studied the alpha decay properties of the two experimentally synthesized isotopes of Meitnerium (Z = 109), ^{275}Mt and ^{276}Mt. The alpha decay half-lives of the isotopes are calculated with the Coulomb and proximity potential model for deformed nuclei (CPPMDN) [1] and the spontaneous fission half-lives are calculated using the shell-effect-dependent formula of Santhosh et al. [2].

Models

- **CPPMDN**

In CPPMDN, the interacting potential between the two deformed nuclei has been taken as the sum of the deformed Coulomb potential, deformed two-term proximity potential and the centrifugal potential. The simple power law interpolation was used for the overlap region.

The Coulomb interaction between the two deformed and oriented nuclei is given as,

$$V_C(r,\theta)=\frac{Z_1Z_2e^2}{r}+3Z_1Z_2e^2\sum_{\lambda,i=1,2}\frac{1}{2\lambda+1}\frac{R_{0i}^{\lambda}}{r^{\lambda+1}}Y_{\lambda}^{(0)}(\alpha_i)\left[\beta_{\lambda i}+\frac{4}{7}\beta_{\lambda i}^2Y_{\lambda}^{(0)}(\alpha_i)\delta_{\lambda,2}\right] \quad (1)$$

with,

$$R_i(\alpha_i)=R_{0i}\left[1+\sum_{\lambda}\beta_{\lambda i}Y_{\lambda}^{0}(\alpha_i)\right] \quad (2)$$

Here $R_{0i}=1.28A_i^{1/3}-0.76+0.8A_i^{-1/3}$ where α_i is the angle between the radius vector and symmetry axis of the ith nuclei. The two-term proximity potential for the interaction between a deformed and spherical nucleus is given by Baltz et. al. as

$$V_{P2}(R,\theta)=2\pi\gamma\left[\frac{R_1(\alpha)R_C}{R_1(\alpha)+R_C+S}\right]^{1/2}\left[\frac{R_2(\alpha)R_C}{R_2(\alpha)+R_C+S}\right]^{1/2} \text{x}$$

$$\left[\left[\varepsilon_0(S)+\frac{R_1(\alpha)+R_C}{2R_1(\alpha)R_C}\varepsilon_1(S)\right]\left[\varepsilon_0(S)+\frac{R_2(\alpha)+R_C}{2R_2(\alpha)R_C}\varepsilon_1(S)\right]\right]^{1/2} \quad (3)$$

where $R_1(\alpha)$ and $R_2(\alpha)$ are the principal radii of curvature of the daughter nuclei at the point where polar angle is α, S is the distance between the surfaces along the straight line connecting the fragments, R_C is the radius of the spherical cluster, $\varepsilon_0(S)$ and $\varepsilon_1(S)$ are the one dimensional slab-on-slab function. Using one dimensional WKB approximation, the barrier penetrability P is given as

$$P=\exp\left\{-\frac{2}{\hbar}\int_a^b\sqrt{2\mu(V-Q)}\,dz\right\} \quad (4)$$

The turning points "*a*" and "*b*" are determined from the equation, V(a)=V(b)=Q. The half life time is given by

$$T_{1/2}=\left(\frac{\ln 2}{\lambda}\right)=\left(\frac{\ln 2}{\nu P}\right) \quad (5)$$

where, $\nu=(\omega/2\pi)=(2E_v/h)$, represents the number of assaults on the barrier per second and λ the decay constant. E_v, is the empirical vibration energy

- **Shell-effect-dependent formula for SF half-lives**

The shell-effect dependent formula for calculating SF half-lives, proposed by Santhosh et al. is given as,

$$\log_{10}(T_{1/2}/yr)=a\frac{Z^2}{A}+b\left(\frac{Z^2}{A}\right)^2+c\left(\frac{N-Z}{N+Z}\right)+d\left(\frac{N-Z}{N+Z}\right)^2+eE_{shell}+f \quad (6)$$

Here a = -43.25203, b = 0.49192, c =3674.3927, d = -9360.6, e = 0.8930 and f =578.56058.

Results and Discussions

The alpha decay properties of the experimentally synthesized ^{275}Mt and ^{276}Mt are studied by comparing the alpha decay half-lives calculated within CPPMDN with the SF half-lives using the shell-effect-dependent formula of Santhosh et al.

Through our study it is seen that the isotopes ^{275}Mt and ^{276}Mt exhibits 3α chains. The experimental half-lives and decay modes matches well with our theoretical predictions. The predictions on the decay modes and half-lives of the isotopes under study are given in Table 1. Experimental Q values are used for calculating the alpha-decay half-lives. The agreement of experimental and theoretical predictions on the decay modes is evident from the table.

Table 1: Predictions on the modes of decay of ^{275,276}Mt

Parent Nuclei	Q_α (MeV)	T_{SF} (s)	$T_{1/2}^{\sim}$ (s)	Mode of Decay Th.	Mode of Decay Exp.
^{275}Mt	10.480	1.177x10^{+00}	1.051x10^{-03}	α	α
^{271}Bh	9.420	7.801x10^{+00}	1.134x10^{-01}	α	α
^{267}Db	7.965†	4.806x10^{+01}	9.557x10^{+02}	SF	SF
^{276}Mt	10.030	1.909x10^{-01}	8.505x10^{-03}	α	α
^{272}Bh	9.180	1.067x10^{+00}	6.414x10^{-01}	α	α
^{268}Db	8.305†	1.363x10^{+01}	4.610x10^{+01}	SF	SF

†Q value calculated using the mass table of Wang et al. [4]

For a theoretical comparison the alpha decay half-lives are calculated using the VSS formula, UNIV, analytical formulae of Royer and UDL. The semi-empirical formula of Xu et al. is also used for finding the SF half-lives.

Figures 1 and 2 represent the comparison of alpha decay half-lives with the SF half-lives using all the theoretical formalisms. A comparison with experimental half-lives is also given. It is clear that the alpha half-lives using all the theoretical formalisms go hand in hand. The agreements with experimental half-lives are evident. Differences can be seen in SF half-lives calculated with the shell-effect-dependent formula and the semi-empirical formula of Xu et al. This may be because of the inclusion of shell correction term in the formula of Santhosh et al.

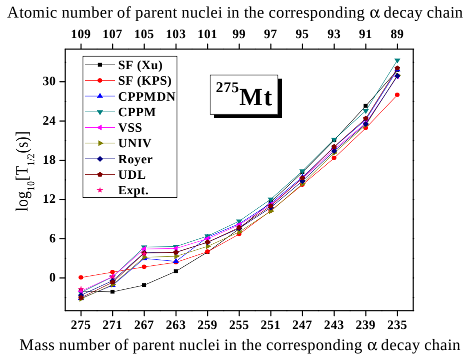

Fig. 1 comparison of alpha decay half-lives with SF half-lives for ^{275}Mt and its decay products

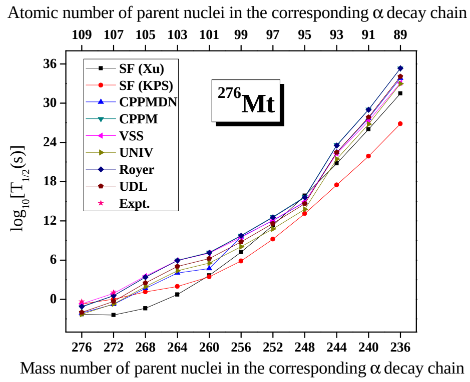

Fig. 2 comparison of alpha decay half-lives with SF half-lives for ^{276}Mt and its decay products

The matching between experimental and theoretical results suggests that the CPPMDN can be used as a good tool for predicting the alpha decay half-lives in superheavy region.

References

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