Alpha and Cluster Decay studies of ^{207,208}Th Isotopes

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Introduction

Heavy nuclei are found to be unstable and decay through various modes like spontaneous fission, alpha decay and cluster radioactivity. The α- decay studies have important role in the development of nuclear physics. It can be described by the quantum tunneling effect through a potential barrier. The spontaneous emission of a nucleus heavier than alpha particle, but lighter than mass of a fragment in fission is known as Cluster radioactivity.

The Cluster Radioactivity was first predicted in 1980 by Sandulescu, Poenaru and Greiner [1] and then it was experimentally confirmed by Rose and Jones in 1984 for the ^{14}C radioactivity from ^{223}Ra [2]. Theoretical models including alpha particle emission model and nuclear fission model are used to explain cluster radioactivity.

The Coulomb and proximity potential model (CPPM) proposed by Santhosh et al. [3,4] has been used extensively for the studies in the areas of alpha decay, cluster decay and spontaneous fission of heavy and superheavy nuclei. ^{207}Th was experimentally produced recently by directing ^{36}Ar to ^{176}Hf. ^{207,208}Th are highly unstable and decay via spontaneous fission or alpha decay [5]. The synthesized heavy isotopes are identified by observing their alpha decay chains.

The theoretical framework

In CPPM, the interaction potential barrier for a parent nucleus undergoing cluster decay is given as;

$$V = \frac{Z_1 Z_2 e^2}{r} + V_p(z) + \frac{\hbar^2 l(l+1)}{2\mu r^2} \quad \text{for } z > 0$$

where Z_1 and Z_2 are the atomic numbers of daughter and emitted cluster; 'r' is the distance between fragment centers, l the angular momentum, μ the reduced mass and V_p is the proximity potential.

The proximity potential is given as;

$$V_p(z) = 4\pi\gamma b\left[\frac{C_1 C_2}{(C_1 + C_2)}\right]\Phi\left(\frac{z}{b}\right)$$

The turning points 'a' and 'b' are given by V(a) = V(b) = Q, where Q is the energy released. The half-life time is given by;

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{\nu P}$$

where, $\nu = 2E_v/h$, represent the number of assaults on the barrier per second and E_v, the empirical zero-point vibration energy.

The Universal Decal Law (UDL)[6] can predict the lighter and heavier cluster emissions because of the inclusion of the preformation and fission like mechanisms. The UDL formula is given as;

$$\log_{10} T_{1/2} = aZ_c Z_d \sqrt{\mu} Q_c^{-1/2} + b\sqrt{\mu Z_c Z_d \left(A_c^{1/3} + A_d^{1/3}\right)} + c$$

Here a = 0.4314, b = -0.4087 and c = -25.7725. Z_c and Z_d are are mass numbers and A_c and A_d are atomic numbers of cluster and daughter.

Results and Discussions

In this study we have computed the half-lives of alpha decay chain of ^{207}Th and ^{208}Th using CPPM. Obtained values are compared with half-lives values calculated based on UDL. The alpha decay energy Q_α released during decay is calculated using the mass excess of the parent, daughter and α- particle taken from the KTUY table.

$Q = \Delta M_p - (\Delta M_\alpha + \Delta M_d) + k(Z^{\varepsilon}_p - Z^{\varepsilon}_d)$. Here ΔM_p, ΔM_d , and ΔM_α represent the mass excess of the parent, daughter, and the α particle respectively. $k(Z^{\varepsilon}_p - Z^{\varepsilon}_d)$ is the term related with electron screening effect on the energy of α particle. Being very small this factor is neglected in our calculation. As per our calculation it was observed that the decay of ^{208,207}Th follows the decay chain ^{208,207}Th→ ^{204,203}Ra→ ^{200,199}Rn→ ^{196,195}Po ^{192,191}Pb→ ^{188,187}Hg→ ^{184,183}Pt→ ^{180,179}Os→ ^{176,175}W → ^{172,171}Hf with half-life ranging from around 10^{-1} seconds to 10^{20}seconds. Half-life values of the α-decay chain up to Pb are shown in Table1and Table 2. From calculations it was observed that the half-life obtained by using CPPM and UDL formula agree with each other. The experimental values are also given in table for comparison.

Table 1: α decay chain of ^{207}Th isotope

	Q (MeV)	$\log_{10} T_{1/2}$ (sec)		
		CPPM	UDL	Expt.
^{207}Th	7.79	-0.75317	-1.2335	-2.01
^{203}Ra	7.74	-1.40503	-1.8819	-1.44
^{199}Rn	7.13	-0.0348	-0.5397	-0.23
^{195}Po	6.76	0.53058	0.00951	0.67
^{191}Pb	5.45	5.68647	5.08575	…….

Table 2: α decay chain of ^{208}Th isotope

	Q (MeV)	$\log_{10} T_{1/2}$ (sec)		
		CPPM	UDL	Expt.
^{208}Th	7.96	-1.3628	-1.8297	-2.36
^{204}Ra	7.64	-1.1044	-1.5552	-1.22
^{200}Rn	6.86	-1.0772	0.4899	0.04
^{196}Po	6.85	0.068	-0.3633	0.75
^{192}Pb	5.22	6.8471	6.3434	……

The cluster decay half-life of ^{207}Th and ^{208}Th isotopes are estimated using the CPPM by inputting the Q-value determined using the KTUY mass table. Of the 104 examined possible clusters, the cluster decay half-lives corresponding to the emission of ^{8}Be, ^{12,13}C, ^{16}O are found to be much less than the experimental upper limit of 10^{30} seconds. Hence there is the probability for emission of these clusters from ^{207}Th and ^{208}Th. The half-life for alpha and cluster emission are also determined using UDL and compared with the predictions of the CPPM. A few results of our calculations are presented Tables 3 and 4. From the tables, one can notice that the predictions of the CPPM and the UDL formula are in good agreement.

Table 3: Cluster decay half-lives of ^{207}Th isotope.

Cluster	Daughter	Q (MeV)	$\log_{10} T_{1/2}$(sec)	
			CPPM	UDL
^{4}He	^{203}Ra	7.79	-0.7532	-1.2335
^{8}Be	^{199}Rn	15.43	19.5073	20.1441
^{12}C	^{195}Po	29.92	19.6919	20.1377
^{13}C	^{194}Po	26.73	28.5585	29.6432
^{16}O	^{191}Pb	43.84	23.4615	22.7266
^{30}Si	^{177}Os	85.23	32.4486	26.6377

Table 4: Cluster decay half-lives of ^{208}Th isotope

Cluster	Daughter	Q (MeV)	$\log_{10} T_{1/2}$(sec)	
			CPPM	UDL
^{4}He	^{204}Ra	8.09	-1.3628	-1.8297
^{8}Be	^{200}Rn	15.35	19.738	20.3846
^{12}C	^{196}Po	29.72	20.0869	20.5398
^{16}O	^{192}Pb	44.12	22.811	22.1442

Conclusions:

We have investigated the alpha decay chains of recently synthesized ^{207,208}Th isotopes. Various possible cluster emissions from these isotopes with decay half-lives within the experimental upper limit are also predicted.

References:

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