Alpha-decay chains study of the new element Z=117

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Introduction

The super heavy mass region in the nuclear chart, is growing fast due to the availability and advancement in the radioactive nuclear beam technology. The stability of these superheavy nuclei depends upon the spherical and/or deformed magicity of the proton and neutron number. The spherical shell closure for the neutron and proton numbers are at 2, 8, 20, 28, 50, and 82 while at 126 it is only for neutron number. Each superheavy element undergoes a characteristic cascade emission of alpha particles before undergoing spontaneous fission. In addition to these decays cluster radioactivity of such elements is also a point of interest. In 1984, Rose and Jones [1] confirmed cluster radioactivity experimentally by the observation of ^{14}C-cluster decay from ^{223}Ra nucleus. Since then number of clusters e.g., ^{14}C, ^{20}O, ^{23}F, $^{22,24-26}$Ne, ^{28,30}Mg and ^{32,34}Si has been observed experimentally from various parents [2, 3].

In this paper, recently observed two isotopes of the element Z=117 with mass number 293 and 294 are studied for the alpha decay and cluster decay characteristics. These two isotopes ^{293}117 and ^{294}117 were produced in the fusion reaction between ^{48}Ca projectile and radioactive target ^{249}Bk nuclei [4]. The PCM model calculations for the ^{293,294}117 alpha decay chains are compared with the experimental results [4] and the macroscopic- microscopic (MM) model dependent calculations of A. Sobiczewski [5]. The most probable cluster decay from all the parents of these two decay chains are seen in the second part of the calculation. The ^{293,294}117 alpha decay chains calculations are based on the Preformed Cluster Model (PCM) which is described briefly and the results of calculation are presented.

Preformed Cluster Model

The preformed cluster model (PCM) uses the dynamical collective coordinates of mass and charge asymmetries η and η_z on the basis of Quantum Mechanical Fragmentation Theory. The decay constant λ in PCM is defined as

$$\lambda = \frac{\ln 2}{T_{1/2}} = P_0 \nu_0 P \qquad (1)$$

Here P_0 is the cluster preformation probability and P is the barrier penetrability which refer, respectively, to the η- and R- motions. ν_0 is the barrier assault frequency. P_0 are the solutions of the stationary Schrodinger equation in η,

$$\left\{-\frac{\hbar^2}{2\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}\frac{1}{\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta} + V_R(\eta)\right\}\psi^{(\nu)}(\eta) = E^{(\nu)}\psi^{(\nu)}(\eta) \qquad (2)$$

Which on proper normalization are given as

$$P_0 = \sqrt{B_{\eta\eta}}\left|\psi^{(0)}(\eta(A_i))\right|^2 \left(2/A\right) \qquad (3)$$

The fragmentation potential $(V_R(\eta)$ in eq (2) is calculated simply as the sum of Coulomb interaction, the nuclear proximity potential and the ground state binding energies of two nuclei:

$$V(R_a,\eta) = -\sum_{i=1}^{2} B(A_i, Z_i) + \frac{Z_1 Z_2 e^2}{R_a} + V_P \qquad (4)$$

With B's taken from the 2003 experimental compilation of Audi et al and from the 1995 calculations of Moller et al. Thus, full shell effects are contained in our calculations that come from the experimental and/or calculated binding energies. The WKB tunneling probability calculated is P= $P_i P_b$ with

$$P_i = \exp\left[-\frac{2}{\hbar}\int_{R_a}^{R_i}\{2\mu[V(R)-V(R_i)]\}^{1/2} dR\right] \qquad (5)$$

$$P_b = \exp\left[-\frac{2}{\hbar}\int_{R_i}^{R_b}\{2\mu[V(R)-Q]\}^{1/2} dR\right] \qquad (6)$$

These integrals are solved analytically for R_b, the second turning point, defined by $V(R_b)$=Q-value for the ground- state decay.

The assault frequency ν_0 is given simply as

$$\nu_0 = \left(2E_2/\mu\right)^{1/2} / R_0 \qquad (7)$$

With $E_2=(A_1/A)Q$, the kinetic energy of lighter fragment, for the Q- value shared between the two products as inverse of their masses.

Calculation and Results

In Table 1 the PCM model calculations for the alpha decays are compared with the experimental results and the macroscopic-microscopic (MM) model calculations. The PCM model calculation for the alpha decay half-lives shows the same trend as in the MM calculations and experimental results but differ in order. This difference in half lives may be due to the consideration of alpha decay in these decay chains from ground state of the parent to the ground state of the daughter, whereas the possibility of alpha-decay from the excited state does also exist [6].

The decay studies show that half-lives of the alpha decay as well as of cluster decay work as a tool in nuclear structure physics to show the presence of shell effects of the parents as well as of daughter nuclei. A higher value of the half-life indicates the presence of shell stabilized parent nucleus, whereas a comparatively low value of half-life tells the same about the daughter and cluster nuclei [7].

References

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TABLE I: Comparison between experimental and calculated PCM α-decay half-lives with Macroscopic-Microscopic calculations (MM).

Parent	P_o^{PCM}	P^{PCM}	Q^{expt} (MeV)	$Log_{10}T_{1/2}^{exp}$ (sec)	Q^{PCM} (MeV)	$Log_{10}T_{1/2}$ (Q^{PCM}) (sec)	$Log_{10}T_{1/2}$ (Q^{exp}) (sec)	Q^{MM} (MeV)	$Log_{10}T_{1/2}$ (Q^{MM}) (sec)
$^{294}117$	6.08×10^{-11}	6.42×10^{-20}	10.959	-1.11	8.964	7.828	3.639	11.15	-1.6678
$^{290}115$	3.48×10^{-9}	1.37×10^{-16}	10.089	-1.80	10.301	2.71	3.1	10.37	-0.3141
$^{286}113$	1.45×10^{-9}	1.97×10^{-17}	9.767	1.293	9.681	3.942	3.772	9.7	0.8822
$^{282}111$	1.65×10^{-9}	1.08×10^{-17}	9.129	-0.2899	9.381	4.154	4.69	9.57	0.589
$^{278}109$	1.43×10^{-9}	6.19×10^{-18}	9.689	0.8822	9.101	4.46	3.336	9.27	0.7853
$^{274}107$	5.06×10^{-10}	6.74×10^{-19}	8.93	1.7329	8.501	5.887	4.944	8.55	2.3265
$^{293}117$	1.97×10^{-7}	1.29×10^{-21}	11.183	-1.837	8.373	6.027	-0.227	11.42	-2.3141
$^{289}115$	5.70×10^{-9}	4.50×10^{-16}	10.455	-0.654	10.601	1.971	2.219	10.63	-0.9831
$^{285}113$	3.64×10^{-8}	8.76×10^{-17}	9.879	0.7385	10.021	1.886	2.152	10.1	-0.2349