Cluster radioactivity from superheavy nuclei

M. S. Unnikrishnan[1],* C. Anjali[1], B. Sanitha[1], and P. Monisha[1]
[1]SVNSS College Vyasagiri (PO),Wadakanchery,Trissur - 680623, Kerala
(Affiliated to University of Calicut)
* email:msdhathan@gmail.com

Introduction

In 1980, Sandulescu et al., predicted cluster radioactivity (CR) on the basis of quantum mechanical fragmentation theory (QMFT), and it was only 4 years later that Rose and Jones could experimentally observe ^{14}C emission from ^{223}Ra using solid state counter telescope. CR is very rare and corresponds to the emission of a nucleus heavier than ^{4}He, but lighter than a typical mass of a light fragment in binary fission (A≥60). CR has been explained making use of several theoretical models, both alpha-like approach and fission-like approach. At present the cluster decay studies from superheavy nuclei (SHN) have of great interest among the theoreticians. The half-lives of cluster decay from various isotopes of heavy nuclei have been calculated using several theoretical models, namely, the Analytical super asymmetric fission model (ASAFM), the Preformed cluster model (PCM), the Coulomb and Proximity potential model (CPPM) [1] etc. Recently, some semi-empirical formulae [2-4], namely, the Universal curve (UNIV) for alpha and cluster decay, Universal decay law (UDL) and the scaling law of Horoi have also been proposed to explain cluster decay.

The UNIV curves are derived by extending the fission theory to larger mass asymmetry. Here, the partial decay half-life T of the parent nucleus is related to the disintegration constant λ of the exponential decay law in time as,

$$\lambda = \ln(2)/T = \nu_S P_S$$

where T is the half-life and ν, S, and P_S are three model-dependent quantities: ν is the frequency of assaults on the barrier per second, S is the pre-formation probability of the cluster at the nuclear surface, and P_S is the quantum penetrability of the external potential barrier. The logarithmic decay half life is given as,

$$\log_{10} T(s) = -\log_{10} P - \log_{10} S + [\log_{10}(\ln 2) - \log_{10} \nu]$$

and

$$-\log_{10} P_S = 0.22873(\mu_A Z_d Z_e R_b)^{1/2} \times [\arccos\sqrt{r} - \sqrt{r(1-r)}]$$

where

$r = R_t / R_b$, $R_t = 1.2249(A_d^{1/3} + A_e^{1/3})$ and $R_b = 1.43998 Z_d Z_e / Q$. Also,

$$\log_{10} S = -0.598(A_e - 1)$$

The Universal decay Law (UDL) for α-decay and cluster decay modes was introduced starting from α-like R-matrix theory. The Universal Decay Law was introduced starting from the microscopic mechanism of the charged particle emission, and it relates the half-life of monopole radioactive decay with the Q values of the outgoing particles as well as the masses and charges of the nuclei involved in the decay. The logarithmic form of UDL is given as,

$$\log_{10}(T_{1/2}) = aZ_c Z_d \sqrt{\frac{A}{Q_c}} + b\sqrt{AZ_c Z_d (A_d^{1/3} + A_c^{1/3})} + c$$

where a, b and c are constants. A is the reduced mass.

According to the model of Horoi $\log_{10} T_{1/2}$ is given as,

$$\log_{10} T_{1/2} = (a_1 \mu^x + b_1)[(Z_1 Z_2)^y / \sqrt{Q} - 7] + (a_2 \mu^x + b_2)$$

where, a_1=9.1, a_2=-10.2, b_1=7.39, b_2=-23.2, x=.416, y=.613. Z_c is the atomic number of cluster, Z_d is the atomic number of daughter nuclei, μ is the reduced mass. Breakdown of scaling law happens as going from cluster decay to fission, because in later case the dynamics is not dominated by coulomb potential.

Results and discussion

The cluster decay process from various superheavy nuclei has been studied using the theoretical models discussed above, thereby investigating the probable cluster decays from the various isotopes of Z=114,115,116,118,123 and 125, which helps in predicting the magic island around N=184. The decay energy of the reaction is given as

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

Here ΔM_p, ΔM_d, ΔM_α are the mass excess of the parent, daughter and cluster respectively.

The plots for $\log_{10}(T_{1/2})$ against the neutron number of the daughter nuclei for the emission of even clusters $^{12,14}C$ and $^{20,22}O$ from the various isotopes of Z=114, 115, 116, 118, 123 and 125, has been shown in Figure 1,2 and 3 respectively. The Fig. 1 (a), (b), (c) and (d) gives the plot for the ^{12}C and ^{14}C emission from the isotopes of Z=114 and Z=115. It can be clearly seen from all these figures that the minima of the logarithmic half lives corresponds to the decay leading to the daughter nuclei with N=184.

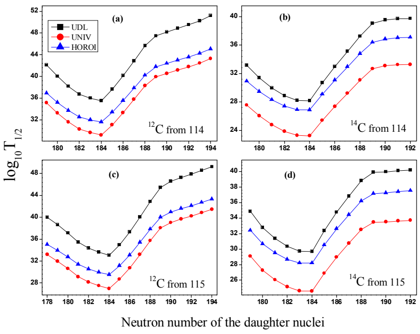

Fig.1. Plot of the computed $\log_{10}(T_{1/2})$ values vs. neutron number of daughter for the emission of clusters ^{12}C and ^{14}C from Z=114 and Z=115.

The Fig. 2 (a), (b), (c) and (d) represents the plot for the ^{22}O and ^{12}C emission from the isotopes of Z=116 and Z=118. From these figures also it is obvious that the minima of the logarithmic half lives corresponds to the decay leading to the daughter nuclei with N=184. The Fig. 3 (a), (b), (c) and (d) represents the plot for the ^{12}C and ^{20}O emission from the isotopes of Z=123 and Z=125. These figures also reveals the fact that the minima of the logarithmic half lives corresponds to the decay leading to the daughter nuclei with N=184. From these observations, it is evident that the neutron magicity at and around N=184 becomes more and more dominant when the parent nuclei are the SHN. Thus, for all the decays considered here, the half life is minimum for the decay leading to a daughter with N=184, which reveals the role of neutron shell closure to be crucial than proton shell closure. As most of the predicted half-lives are well within the present upper limit for measurements, the predictions on the cluster decay half-lives of these SHN may open up a new pathway for further experimental investigations in the superheavy region.

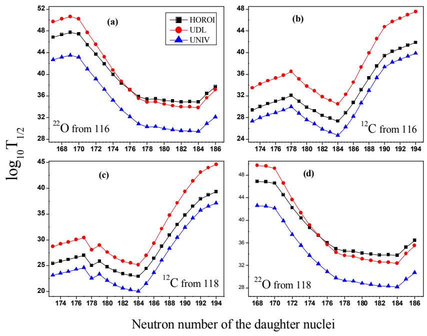

Fig.2. Plot of the computed $\log_{10}(T_{1/2})$ values vs. neutron number of daughter for the emission of clusters ^{22}O and ^{12}C from Z=116 and Z=118.

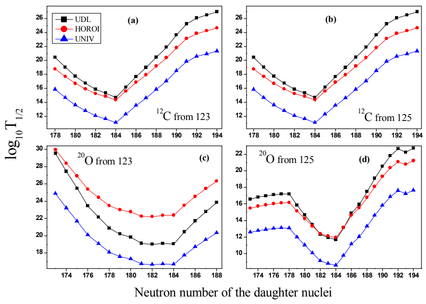

Fig.3. Plot of the computed $\log_{10}(T_{1/2})$ values vs. neutron number of daughter for the emission of clusters ^{12}C and ^{20}O from Z=123 and Z=125.

Acknowledgement

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