Neutron magicity in cluster radioactivity

M. S. Unnikrishnan*, K.Hariprabha and Jessy K Benny
SVNSS College Vyasagiri (PO),Wadakanchery,Trissur-680623, kerala
(Affiliated to University of Calicut)
** email: msdhathan@gmail.com*

Introduction

Cluster radioactivity is the spontaneous emission of fragments heavier than alpha particles. It was first experimentally detected by Rose and Johns [1] in 1984 in the radioactive decay of ^{14}C from ^{223}Ra. After this, several clusters were observed experimentally from various parents in the trans-lead region with partial half lives from 10^{11} up to 10^{30}s.

Cluster radioactivity has been explained making use of several theoretical models, both alpha-like approach and fission-like approach. The Coulomb and proximity potential (CPPM) has been used for extensive studies on this area [2]. Through this work it is intended to investigate the ^{22}F and ^{22}O cluster decays of uranium and curium isotopes. For the calculation, we used the Universal (UNIV) curve [3] and compared it with Universal decay law (UDL) [4] and the scaling law of Horoi [5].

Universal (UNIV) curves are derived by extending the fission theory to larger mass asymmetry. They are based on the quantum mechanical tunneling process relationship of the disintegration constant λ and 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

$$\lambda = \ln 2 / T = \nu S P_S \tag{1}$$

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 (equal to the penetrability of the internal part of the barrier in a fission theory and P_s is the quantum penetrability of the external potential barrier

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

and

$$-\log_{10} P_S = 0.22873(\mu_A Z_d Z_e R_b)^{1/2} \times [\arccos\sqrt{r} - \sqrt{r(1-r)}] \tag{3}$$

$$\log_{10} S = -0.598(A_e - 1) \tag{4}$$

where

$r = R_t / R_b$, $R_t = 1.2249(A_d^{1/3} + A_e^{1/3})$ and

$R_b = 1.43998 Z_d Z_e / Q$

A new Universal Decay Law (UDL) for *α*-decay and cluster-decay modes was introduced starting from *α*-like *R*-matrix theory. UDL makes it possible to represent the same plot with a single straight line the logarithm of the half-lives versus one of the two parameters (*χ*' and *ρ*') that depend on the atomic and mass numbers of the daughter and emitted particles as well as the *Q* value. The Universal Decay Law was introduced starting from the microscopic mechanism of the charged-particle emission. The UDL 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 Universal Decay Law (UDL) can be written in the logarithmic form as

$$\log_{10}(T_{1/2}) = aZ_c Z_d \sqrt{\frac{A}{Q_c}} + b\sqrt{AZ_c Z_d (\mathrm{A}_d^{1/3} + \mathrm{A}_c^{1/3})} + c \tag{5}$$

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

According to HOROI model $\log_{10}T_{1/2}$ is given

$$\log_{10} T_{1/2} = (a_1 \mu^x + b_1)[(Z_1 Z_2)^y / \sqrt{Q} - 7] + (a_2 \mu^x + b_2) \tag{6}$$

where a_1=9.1, a_2=-10.2, b_1=7.39, b_2=-23.2, x=0.416, y=0.613. 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 dynamic is not dominated by coulomb potential.

Results and discussions

The cluster decay half lives in the emission of clusters ^{22}F and ^{22}O from parents $^{217-248}$U and $^{232-252}$Cm nuclei have been calculated by using UNIV, UDL and HOROI. The decay energy of the reaction is given as

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

Here ΔM, ΔM_1, ΔM_2 are the mass excess of the parent, daughter and cluster respectively. The Q values for cluster decay are calculated using the experimental mass excess values of Audi et al. The decay will occur spontaneously only if Q>0.

The cluster decay half lives calculated using, UNIV, UDL and the scaling law of Horoi and their comparisons are shown in Figure 1and 2. The emission of ^{22}O and ^{22}F respectively from $^{232\text{-}252}$Cm and $^{217\text{-}238}$U are given in the plots. Here the graphs are plotted between the neutron number of the daughter nuclei and the logarithmic half lives. Here the minima of the logarithmic half lives are found for the decay ^{22}O and ^{22}F from $^{217\text{-}238}$U is near doubly magic ^{216}Po (Z = 84, N = 126) and ^{209}Bi (Z = 83, N = 126). For the cluster emission of ^{22}O and ^{22}F from $^{232\text{-}252}$Cm leading to $^{210\text{-}230}$Ra and $^{208\text{-}228}$Fr with minimum logarithmic half life of ^{214}Ra (Z = 88, N = 126) and ^{213}Fr (Z = 88, N = 126). Of these plots, the odd-even staggering (OES) is prominent in ^{22}F decay from U and Cm. The abrupt changes in binding energy as one goes from a nucleus with an even number of neutrons (or protons) to its neighbour with an odd number of nucleons are known as odd-even-stagger (OES). The odd-even-stagger (OES) in atomic nuclei is usually attributed to the existence of nucleonic pairing correlations.

Conclusion

Using UNIV model cluster decay half lives has been calculated for $^{217\text{-}238}$U and $^{232\text{-}252}$Cm isotopes also compared it with UDL and Scaling law of HOROI. It is found that they match well over a wide range. It has been seen that $\log_{10}(T_{1/2})$ is minimum for those nuclei whose daughter nuclei having neutron number 126 and 126 is a magic number. Our study reveals the role of magic daughter nuclei in cluster decay process and also reveals the fact that the role of neutron shell closure is crucial than proton shell closure. The odd-even staggering (OES) are found to be more prominent in the emission of odd clusters.This observation also will serve as a guide to the future experiments. The odd-even staggering (OES) are found to be more prominent in the emission of odd clusters.

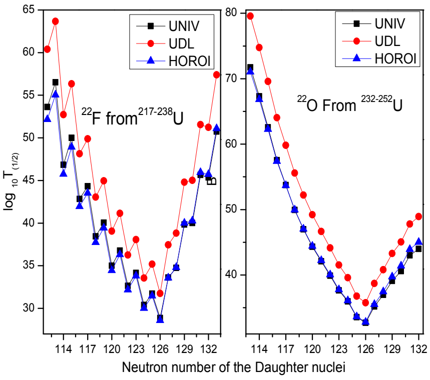

Fig.1. Plot of the computed $\log_{10}(T_{1/2})$ values vs. neutron number of daughter for the emission of clusters ^{22}F and^{22}O from U isotopes.

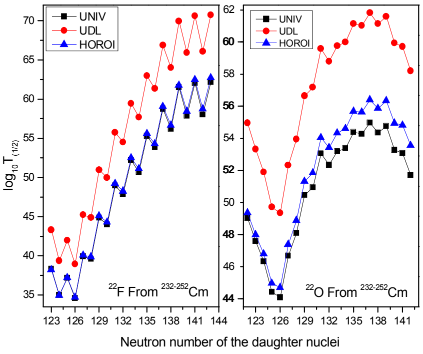

Fig.2. Plot of the computed $\log_{10}(T_{1/2})$ values vs. neutron number of daughter for the emission of clusters ^{22}F and^{22}O from Cm isotopes.

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References

[1] H. J. Rose and G. A. Jones, Nature **307** 245 (1984)

[2] K. P. Santhosh, B. Priyanka and M. S. Unnikrishnan, Nucl. Phys. A 889, 29 (2012)

[3] D. N. Poenaru, R. A. Gherghescu and W. Greiner, Phys. Rev. C **83** 014601 (2011).

[4] C. Qi et al, Phys. Rev. C **80** 044326 (2009).

[5] M. Horoi, arXiv:nucl-th/9403008v1 (1994).