Exploration of the decay channels within fragmentation profile of radioactive nuclei

Manjot Kaur[1,*], Sarbjeet Kaur[2], Jagtar Singh[1], Sukhjeet Singh[1], and BirBikram Singh[1,2,$]

[1]*Department of Physics, Akal University, Talwandi Sabo, Bathinda-151302, INDIA*
[2]*Department of Physics, Sri Guru Granth Sahib World University, Fatehgarh Sahib-140406, INDIA*
*Email: * sidhumanjot198@gmail.com, $bir_ phy@auts.ac.in*

Introduction

The discovery of radioactivity by H. Becquerel in 1896 and subsequently studies by Pierre Curie, Marie Curie, Rutherford and many others contributed immensely to our understanding of nuclear phenomena and properties. The two radioactivities (α and β) and nuclear fission are the classical types of nuclear decays. After another four decades from the discovery of fission, a new kind of radioactivity i.e. cluster radioactivity, the spontaneous emission of fragments heavier than alpha particle, is established on theoretical front [1] followed by its experimental confirmation in 1984 [2]. All the above mentioned decay modes, i.e., α decay, cluster decay and fission are treated as different aspects of ground state decay of nuclear systems.

A number of theoretical models and theories have been developed to describe the above mentioned spontaneous decays, one of which is preformed cluster decay model (PCM) [3-5]. Within PCM, all the decay modes are treated on equal footing based on two stage processes. Firstly, a particular decay channel has to preform followed by second stage of penetration of the potential barrier, respectively, evaluated as preformation and penetration probabilities.

In the present work, we have explored these competing decay modes within fragmentation profile of radioactive nuclei $^{232,234,236,238}U$, within PCM. The role of nuclear proximity potential, Coulomb potential along with that of the binding energies has been investigated in the total fragmentation potential of these radioactive nuclei.

Methodology:

The PCM [3-5] uses the dynamical collective coordinates of mass and charge asymmetries η_A and η_z on the basis of quantum mechanical fragmentation theory. The decay constant λ in PCM is defined as

$$\lambda_{PCM} = \ln 2/T_{1/2} = \nu_0 P_0 P. \quad (1)$$

where P_0, P and ν_0 are preformation probability, penetrability and barrier assault frequency, respectively. The P_0, we get by solving stationary Schrodinger equation

$$\left\{-\frac{\hbar^2}{2\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}\frac{1}{\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}+V_R(\eta)\right\}\Psi_R^{(\nu)}(\eta)=E_R^{(\nu)}\Psi_R^{(\nu)}(\eta) \quad (2)$$

The collective fragmentation potential $V_R(\eta)$ used in eq. 2 is calculated within Strutinsky renormalization procedure, T-dependent liquid drop energy V_{LDM} is taken from Davidson et al. and empirical shell corrections δU of Myres and Swiatecki and including T- dependence nuclear proximity V_P, and Coulomb V_C potential

$$V(\eta,R) = -\sum_{i=1}^{2} B_i(A_i,Z_i)+V_c(R,Z_i)+ V_p(R,A_i) \quad (3)$$

i.e. it is the sum of binding energies (B_i), coulomb(V_c), proximity(V_p).

Calculations and Discussions:

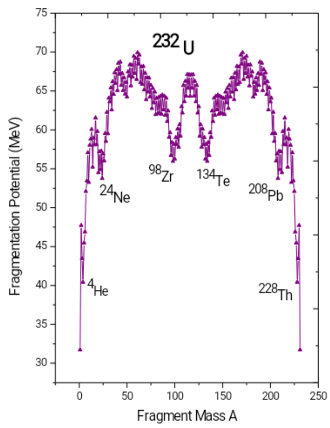

Fig. 1(a) *The Fragmentation Profile of ^{232}U.*

In order to explore the comparative evolution of fragmentation scenario with increasing mass number of parent nuclei, the fragmentation potential of $^{232,234,236,238}U$ nuclei have been studied. We note that α-decay is more dominant

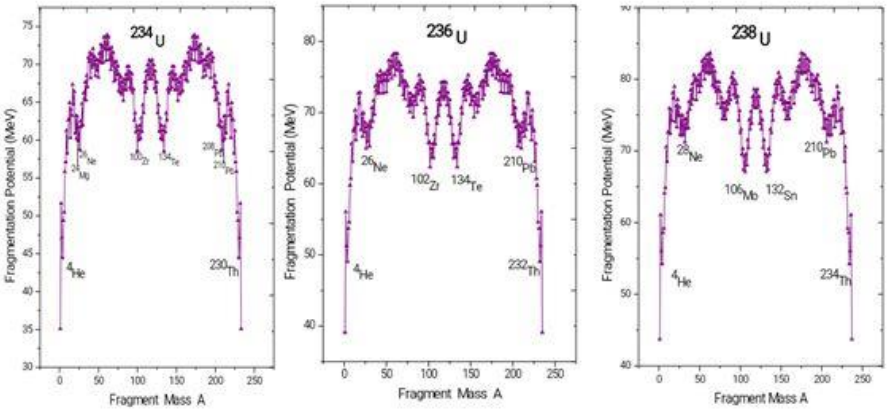

Fig. 1(b-d) *The Fragmentation Profile of ^{234,236,238}U.*

out of cluster decay and spontaneous fission. The magnitude of fragmentation potential, for all three probable decay modes, is found to increase with an increase in mass number of parent nuclei. It shows that the heavier isotopes of U are more unstable and hence more prone to decay.

From Fig. 1(a-d), we note that for ^{232}U parent nucleus, the cluster emission with doubly magic ^{208}Pb daughter is more probable than spontaneous fission. With increasing mass of parent nucleus, the spontaneous fission with ^{134}Te fragment having neutron magic number N = 82 supersedes the cluster decay for heavier ^{234,236}U nuclei. However, for ^{238}U the doubly magic ^{132}Sn spontaneous fission fragment with ^{106}Mo complementary fragment clearly surpass the cluster radioactive decay mode. In other words, the asymmetric mass fragmentation becomes more pronounced with increasing mass number/ neutron number of parent radioactive nucleus.

S. No.	Parent Nucleus	Decay Modes *(QMFT)*			Decay Modes *(Experimental)*
		Alpha Decay	Cluster Decay	Spontaneous Fission (SF)	
1.	^{232}U	^{4}He+^{228}Th	^{24}Ne+^{208}Pb	^{98}Zr+^{134}Te	Alpha, SF- 3 x 10^{-12} %
2.	^{234}U	^{4}He+^{230}Th	^{26}Ne+^{208}Pb ^{24}Mg+^{210}Hg	^{100}Zr+^{134}Te	Alpha, SF- 1.6 x 10^{-9} % Cluster Mg -1 x 10^{-11} % Cluster Ne - 9 x 10^{-12} %
3.	^{236}U	^{4}He+^{232}Th	^{26}Ne+^{210}Pb	^{102}Zr+^{134}Te	Alpha, SF- 9.4 x 10^{-8} %
4.	^{238}U	^{4}He+^{234}Th	^{28}Ne+^{210}Pb	^{106}Mo+^{132}Sn	Alpha, SF - 5.5 x10^{-5} %

Table1 *The decay modes of even-A $^{232\text{-}238}$U nuclei and experimental data for the observed decay modes [6].*

The above discussed results are also listed in the Table 1. The theoretical results within QMFT are also shown alongside experimental data by National Nuclear Data Center [6]. In all considered nuclei, alpha decay is the most feasible whereas cluster decay and the spontaneous fission compete with each other. For ^{232}U nucleus, the closed shell effects of doubly magic nuclei ^{208}Pb for cluster decay of ^{24}Ne and ^{134}Te (semi-magic nucleus) + ^{98}Zr spontaneous fission fragments are clearly depicted in terms of strong minima in the potential energy surface. The same result holds for ^{234,236,238}U. The spontaneous fission starts dominating with increasing mass of Uranium isotopes. In other words, spontaneous fission is more preferred than cluster decay for neutron-rich isotopes. Work is in progress.

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