Role of neutron magicity in the cluster radioactivity

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Introduction

Exotic decay or cluster radioactivity was first predicted by Sandulescu et al., in 1980 [1] and such decays was first observed experimentally by Rose and Jones in 1984 [2] in the radioactive decay of ^{223}Ra by the emission of ^{14}C with a half life of 3.7 ± 1.1 years. Later on, 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.

In the present paper we have investigated the cluster decay process ^{15}N from $^{206\text{-}230}$Ac, ^{23}F from $^{212\text{-}238}$Pa, ^{25}Ne from $^{217\text{-}240}$U and ^{29}Mg from $^{217\text{-}239}$U. We have considered all the parent-cluster combinations, where the experimental results were available.Calculations are done with the Coulomb and proximity potential model (CPPM) predicted by Santhosh et al., [3]

The comparisons of our calculations with the values obtained using Universal (UNIV) curve [4], Universal decay law (UDL) [5] and the scaling law of Horoi [6] is also done.

The Coulomb and proximity potential model (CPPM)

In CPPM, the potential energy barrier is taken as the sum of Coulomb potential, proximity potential and centrifugal potential for the touching configuration and for the separated fragments. For the pre-scission region, simple power law interpolation was used. The inclusion of proximity potential reduces the height of the potential barrier, which closely agrees with the experimental result.

The interacting potential barrier for two spherical nuclei is given by

$$V = \frac{Z_1 Z_2 e^2}{r} + V_p(z) + \frac{\hbar^2 \ell(\ell+1)}{2\mu r^2}$$

Here Z_1 and Z_2 are the atomic numbers of the daughter and emitted cluster, 'z' is the distance between the near surfaces of the fragments, 'r' is the distance between fragment centers, ℓ represents the angular momentum, μ the reduced mass, V_P is the proximity potential given by Blocki *et al.*,

Using one dimensional WKB approximation, the barrier penetrability P is given as

$$P = \exp\left\{-\frac{2}{\hbar}\int_a^b \sqrt{2\mu(V-Q)}\,dz\right\}$$

The turning points "a" and "b" are determined from the equation, V(a)=V(b)=Q.

The half life time is given by

$$T_{1/2} = \left(\frac{\ln 2}{\lambda}\right) = \left(\frac{\ln 2}{\upsilon P}\right)$$

where, $\nu=(\omega/2\pi)=(2E_v/h)$, represents the number of assaults on the barrier per second and λ the decay constant. E_v, is the empirical vibration energy.

Results and discussions

The cluster decay half lives in the emission of clusters ^{15}N, ^{23}F, ^{25}Ne and ^{29}Mg from various parents $^{206\text{-}230}$Ac, $^{212\text{-}238}$Pa, $^{217\text{-}240}$U and $^{217\text{-}239}$U leading to doubly magic ^{208}Pb and neighbouring nuclei have been calculated by using CPPM. The decay energy of the reaction is given as

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

The Q values for cluster decay are calculated using the experimental mass excess values of Audi *et al.*, and the possibility to have a cluster decay process is related to its exotermicity, $Q > 0$. Here ΔM_p, ΔM_d, ΔM_α are the mass excess of the parent, daughter and cluster respectively.

The $T_{1/2}$ values for the respective cluster decays are calculated using the Universal (UNIV) curve and the Universal decay law (UDL) for alpha and cluster decay modes and the Scaling Law of Horoi et al., for cluster decay and are compared with CPPM values. The cluster decay half lives calculated using CPPM, UNIV, UDL and the scaling law of Horoi and their comparisons are shown in Figure 1. The plots for $\log_{10}(T_{1/2})$ against the neutron number of the daughter in the cluster emission of the odd clusters ^{15}N, ^{23}F, ^{25}Ne and ^{29}Mg respectively from $^{206-230}Ac$, $^{212-238}Pa$, $^{217-240}U$ and $^{217-239}U$ are given in these figures. Here the minima of the logarithmic half lives are found for the decay leading to the doubly magic ^{208}Pb (Z = 82, N = 126) for the cluster emission of ^{15}N from ^{223}Ac, ^{23}F from ^{231}Pa, ^{25}Ne from ^{233}U; and for the decay leading to the near doubly magic ^{206}Hg (Z = 80, N = 126) for the cluster emission of ^{29}Mg from ^{235}U. Of these plots, it can be seen that plots for the emission of the odd clusters i.e. ^{25}Ne from $^{217-240}U$ and ^{29}Mg $^{217-239}U$ reveal the odd-even staggering (OES). 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 the Coulomb and proximity potential model (CPPM) cluster decay half lives has been examined in detail for $^{206-232}Ac$, $^{212-238}Pa$, $^{217-241}U$ isotopes. The results thus obtained were compared with the corresponding experimental data and with the values of UNIV, UDL and the scaling law of Horoi and it is found that they match well over a wide range. For most of the parent-cluster combinations the computed half lives are within the present experimental limits for measurements. 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 mass clusters. Our study reveals the role of doubly magic ^{208}Pb daughter nuclei in cluster decay process and also reveals the fact that the role of neutron shell closure is crucial than proton shell closure.

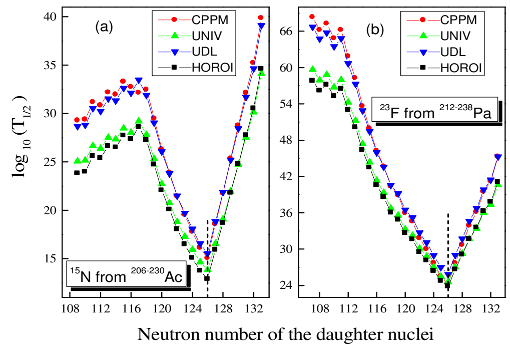

Fig.1. Plot of the computed $\log_{10}(T_{1/2})$ values vs. neutron number of daughter for the emission of clusters ^{15}N and ^{23}F from Ac and Pa isotopes.

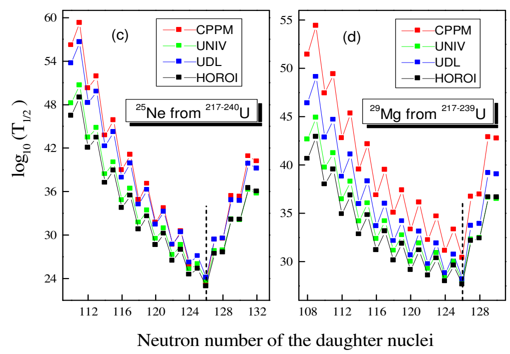

Fig.2. Plot of the computed $\log_{10}(T_{1/2})$ values vs. neutron number of daughter for the emission of clusters ^{25}Ne and ^{29}Mg U isotopes.

References

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