Empirical formula for the cluster formation probability for the isotopes in heavy region

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Introduction

The Emission of Particle heavier than alpha particle is known as cluster radioactivity. There are two significant models to explain the observed or predicted cluster decay modes. In one case, within the Gamow theory[1], the cluster/alpha particle is preborn individually within the decaying nucleus before it could penetrate through the potential barrier[2] with the available Q value and with a definite preformation probability. So this is called the Preformed Cluster model (PCM) [3,4], in which the potential is numerically set up by the double-folding model for both Coulomb and nuclear parts. It is a further modification of Gamow's theory for alpha decay. Hence clusters with different sizes have different preformation probabilities and different assault frequencies. In this model, the decay width is given as the product of three independent quantities, the preformation probability of the emitted cluster within the parent nucleus, the assault frequency, and the barrier penetrability.

$$\lambda_{PCM} = P_0 \upsilon P \qquad (1)$$

The present work aims to develop a new empirical formula for the estimation of the preformation probability associated with the formation of different clusters inside the parent nuclei in the heavy region.

Empirical formula for Preformation Probability

we should identify the factors that have a direct dependence on the preformation probability. Blendowsky et al. [5] has already been suggested the spectroscopic factor in the case of cluster decay as

$$S = S0(\propto)^{(Ac-1)/3} \qquad (2)$$

Here the logarithmic spectroscopic factor has a linear dependence on the factor 'Ac,' the fragment's mass. Similarly, we have identified the factors directly depending on the preformation probability and analyzed their linear relationship with $\log_{10}(P_0)$. That means the plot of $\log_{10} S$ against the depending factor should be a straight line.

So from the previous studies on alpha and cluster preformation probability, we have identified such physical quantities that have a direct dependence on P_0. The shell effect is an essential factor while considering the preformation study [6], and hence we have included the Q value of the reaction. $(Q)^{1/2}$ has a linear relationship with the preformation probability.

So from all these, it is very much clear that the parameters depending on preformation probability for clusters are the Q-value of the reaction, charge and mass asymmetry, the cluster mass Ac, and also the cluster, daughter atomic numbers Zc and Zd. These parameters are used to develop a phenomenological formula for determining the cluster preformation probability. However, researchers have already deduced the relationship of P_0 with various quantities, as mentioned above; we have used a different form.

By analyzing the factors affecting preformation probability, we can suggest a phenomenological expression that can give the cluster preformation probability as

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Parent	Cluster	Q value	Preformation	
			present	Eqn. 4
^{221}Fr	^{14}C	28.93	4.15E-10	1.55E-08
^{221}Ra	^{14}C	30.82	4.24E-10	1.59E-08
^{222}Ra	^{14}C	31.32	4.26E-10	9.81E-10
^{223}Ra	^{14}C	29.70	4.19E-10	1.52E-08
^{224}Ra	^{14}C	28.36	4.12E-10	9.38E-10
^{223}Ac	^{14}C	31.69	4.28E-10	1.56E-08
^{225}Ac	^{14}C	28.76	4.14E-10	1.49E-08
^{226}Ra	^{14}C	26.21	4.01E-10	8.97E-10
^{230}Th	^{14}C	24.85	3.94E-10	8.65E-10
^{234}U	^{14}C	25.36	3.96E-10	8.35E-10
^{236}Pu	^{14}C	26.91	4.04E-10	8.40E-10
^{238}Cm	^{14}C	28.01	4.09E-10	8.43E-10
^{240}Cf	^{14}C	29.11	4.14E-10	8.46E-10
^{228}Th	^{20}O	42.76	4.83E-13	2.34E-13
^{231}Pa	^{23}F	50.52	1.63E-14	8.67E-14
^{222}Ra	^{24}Ne	48.63	5.13E-15	7.26E-15
^{226}Ra	^{24}Ne	50.76	5.21E-15	5.58E-15
^{228}Th	^{24}Ne	55.48	5.37E-15	5.64E-15
^{230}Th	^{24}Ne	56.63	5.41E-15	4.98E-15
^{231}Pa	^{24}Ne	58.80	5.48E-15	7.93E-14
^{232}U	^{24}Ne	61.17	5.55E-15	5.03E-15
^{233}U	^{24}Ne	59.51	5.50E-15	7.49E-14
^{234}U	^{24}Ne	58.00	5.45E-15	4.45E-15
^{236}Pu	^{24}Ne	59.42	5.49E-15	4.49E-15
^{238}Pu	^{24}Ne	57.03	5.40E-15	3.99E-15
^{242}Cm	^{24}Ne	57.19	5.40E-15	3.59E-15
^{244}Cf	^{24}Ne	58.73	5.45E-15	3.61E-15
^{234}U	^{26}Ne	75.18	6.01E-16	1.67E-16
^{222}Ra	^{28}Mg	60.73	5.64E-17	2.60E-16
^{226}Ra	^{28}Mg	60.98	5.64E-17	1.82E-16
^{228}Th	^{28}Mg	66.58	5.82E-17	1.87E-16
^{232}U	^{28}Mg	73.21	6.01E-17	1.61E-16
^{234}U	^{28}Mg	73.72	6.02E-17	1.36E-16
^{235}U	^{28}Mg	72.04	5.97E-17	1.99E-15
^{236}U	^{28}Mg	70.47	5.92E-17	1.16E-16
^{236}Pu	^{28}Mg	79.29	6.18E-17	1.39E-16
^{238}Pu	^{28}Mg	75.64	6.07E-17	1.19E-16
^{242}Cm	^{28}Mg	75.21	6.05E-17	1.04E-16
^{244}Cf	^{28}Mg	77.75	6.12E-17	1.05E-16
^{246}Fm	^{28}Mg	79.98	6.18E-17	1.07E-16
^{250}Fm	^{28}Mg	77.33	6.10E-17	7.98E-17
^{252}Fm	^{28}Mg	76.38	6.07E-17	6.91E-17
^{238}U	^{34}Si	85.55	6.47E-20	2.89E-19
^{242}Cm	^{34}Si	96.61	6.75E-20	2.98E-19
^{238}Pu	^{30}Mg	76.42	6.11E-18	6.29E-18

Table1. The comparison of computed cluster formation probabilities for various clusters emitted from heavy parents.

$$P_0 = [\, aQ^{1/2} + \frac{b}{\eta_A} + \frac{c}{\eta_Z} \,]*10^{-Ac/2} \qquad (3)$$

Where η_A and η_Z represent the charge and mass assymitries and the parameters a =0.0005174, b =0.000668 and c =0.0005202.

Result and discussion

We have estimated the cluster preformation probabilities of ^{14}C, ^{20}O, ^{23}F, ^{24,26}Ne, ^{28,30}Mg and ^{34}Si from various heavy parents based on the present formula given in eqn. (3) and is given in Table 1. Here the Q values are calculated from the mass excess values that are taken from the atomic mass table of Wang et al.[7].

D.Ni and Z. Ren [8,9] proposed a generalized density-dependent cluster model to study the cluster decay in even- even and odd A nuclei. They have taken into account the preformation probability which is calculated by an empirical formula in terms of cluster mass A_c or charge numbers Z_c or Z_d and is given by

$$P0(c) = 10^{-a\sqrt{\mu}(Zc.Zd)^{\frac{1}{2}}+b} \qquad (4)$$

Where $\mu = (A_c*A_d)/(A_c + A_d)$, and the parameters $a = -0.052$

b (e−e) = 0.690, b (o−A) = −0.600

The last column of the Table 1 represents the computed cluster formation probability of ^{14}C, ^{20}O, ^{23}F, ^{24,26}Ne, ^{28,30}Mg and ^{34}Si from various heavy parents using eqn. (4). It is obvious from the table that the present formula predictions are in good agreement with the formula predictions of D. Ni et al.

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