Cluster radioactivity of neutron deficient Er isotopes in the fission model approach

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Introduction

Cluster radioactivity is commonly observed in the mass region A>220 [1]. Still, many cluster decays are reported in the lower mass regions also, especially between 150 and 190 [2]. It has been established that the cluster emission rate from odd parent nuclei is in many cases hindered as compared to the ones measured for the cluster emission from the neighbouring even-even isotopes [3]. Moreover, the observed decays, where the parent and daughter nuclei have odd mass are less in number [4].

In most of the works carried out in the field of cluster radioactivity, the parent, daughter and cluster are assumed to be spherical. In the mass range 150<A<190 and A>220, many nuclei are found to be deformed in their ground state [5]. In the present study, we have made an attempt to predict the feasibility of cluster radioactivity from neutron deficient Erbium isotopes. The half lives ($T_{1/2}$) relevant to cluster decay of all isotopes of Erbium from A=150 to 170 are calculated using fission model potential. The measurable upper limit of half life is fixed at 10^{40} sec and the instability against different cluster decays is studied. The minimum half lives confirm the role of closed shell effects in cluster emission.

Theory

Cluster radioactivity refers to the spontaneous emission of clusters heavier than alpha particles from nuclei or it is a very asymmetric fission mode. The process of cluster radioactivity can be explained either using the preformed cluster model (PCM) of Gupta and collaborators [6] or the fission model of Poenaru etal [7]. In PCM,the preformation factor P_0 is calculated. Here, half life calculations are performed using fission model potential. Cluster emission occurs only when the parent is in a metastable state. The preformation factor P_0 is assumed to be 1 and during cluster emission, the nucleus undergoes gradual shape changes. In fission model calculations, the four independent coordinates selected [2] are the radii of each spherical fragment R_1 and R_2, the height of the largest segment ξ and the distance between their geometric centres ζ.

Here, we simplified the problem to a one dimensional one. The barrier penetrability factor P is estimated using the one dimensional WKB approximation as:

$$P = exp(-2/\hbar \int_{\zeta_0}^{\zeta_c} [2\mu(V-Q)]^{1/2} d\zeta) \quad (1)$$

with ζ_0 and ζ_c being the inner and outer turning points respectively and Q the Q-value of the decay. The potential V is the effective liquid drop one [8]. To determine the inertial coefficient μ, the Werner-Wheeler approximation is made use of. The decay rate

$$\lambda = \lambda_0 P \quad (2)$$

with $\lambda_0 = 10^{22}$ - the assault frequency. The half life is calculated as:

$$T_{1/2} = log2/\lambda \quad (3)$$

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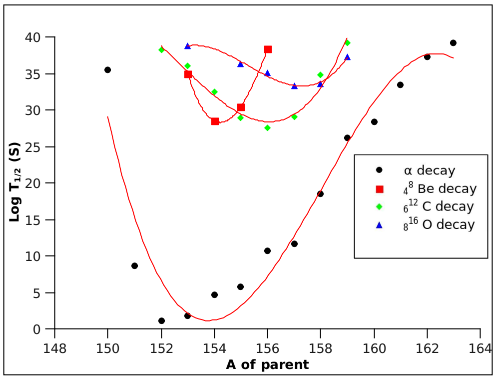

FIG. 1: Plots of log $T_{1/2}$ against mass number of parent for different clusters

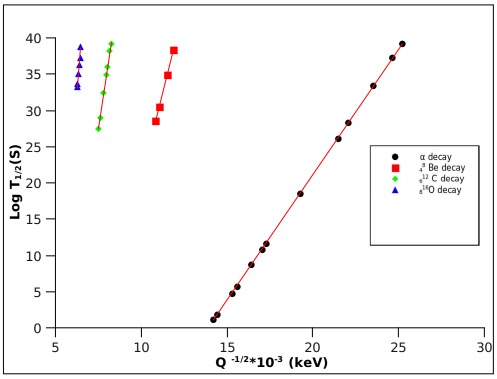

FIG. 2: Geiger Nuttal plots for different clusters

TABLE I: Slopes and Y intercept values of Geiger-Nuttal plots for different clusters from various Erbium isotopes

Cluster	Intercept Y	Slope X
^{4}He	-48.3749	3471.5243
^{8}Be	-72.2947	9312.2115
^{12}C	-93.5895	16118.1649
^{16}O	-123.2998	24990.3338

Results and discussion

Fig 1 gives the variation of log $T_{1/2}$ with respect to the mass number of parent. It is found that upto A=163, Erbium isotopes are weakly or strongly unstable against alpha decay, but above that they are stable. Erbium isotopes with $153 \leq A \leq 156$ and $152 \leq A \leq 159$ are seem to be unstable against ^8_4Be decay and $^{12}_6C$ decay respectively. In the case of $^{16}_8O$ decay, Erbium isotopes with $153 \leq A \leq 159$ except $A = 154$ are unstable. ^{152}Er, ^{154}Er and ^{156}Er isotopes have the minimum half lives for alpha, ^{8}Be and ^{12}C decay respectively whereas ^{157}Er and ^{158}Er have got the minimum half life for ^{16}O decay. In each of these decay,the daughter has a magic or near magic number of neutrons(81 or 82) and the proton number is in the neighbourhood of midway between magic numbers. This points out the significance of shape (β values) of the daughter nucleus in addition to their magicity. In figure 2, log $T_{1/2}$ is plotted against $1/\sqrt{Q}$, which verifies Geiger Nuttal law:

$$logT_{1/2} = \frac{X(Z_2)}{\sqrt{Q}} + Y(Z_2) \qquad (4)$$

where, Z_2 is the proton number of cluster. The values $X(Z_2)$ and $Y(Z_2)$ are obtained by:

$$\begin{aligned} X(Z_2) &= 22.9364{Z_2}^3 - 154.5791{Z_2}^2 + \\ &\quad 3205.5975Z_2 - 2504.8460 \qquad (5) \end{aligned}$$

and

$$\begin{aligned} Y(Z_2) &= -0.2300{Z_2}^3 + 3.0883{Z_2}^2 - \\ &\quad 24.0491Z_2 - 10.7896 \qquad (6) \end{aligned}$$

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