A feasibility study of cluster radioactivity from Gd

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Introduction

It has been indicated by phenomena such as alpha decay and cluster radioactivity that nucleons tend to cluster in groups within nuclei. A cluster is a spatially localised subsystem which is composed of strongly correlated nucleons. The idea of a cluster model of a light nucleus was first proposed by Hafstad and Teller [1]. Alpha particle cluster is the most probable one. Other clusters are also expected from different nuclei. Spontaneous emission of clusters heavier than alpha particle and lighter than the lightest fission fragment from a nucleus is termed cluster radioactivity. Rose and Jones[2] first observed this natural radioactivity in the emission of ^{14}C from ^{223}Ra. The aim of the present study is to investigate the feasibility of cluster radioactivity from proton rich nuclei Gd.

Theoretical model

In this study we used the Effective Liquid Drop Model (ELDM). Here the alpha decay and cluster radioactivity are explained taking into account different inertial coefficients according to the shape parameterization chosen to describe the dynamical evolution of the nuclear system [3]. The multidimensional evolution of the system is reduced to the one-dimensional one by assuming the geometrical constraint necessary to preserve the adopted shape during the whole process and to keep the total volume of the system constant. From the resulting one-dimensional problem the Gamow penetrability factor is calculated by using an effective mass, determined from the Werner-Wheeler approximation[4]. The effective liquid drop scheme includes shell effect in the surface potential, defining the surface tension of the drop in terms of the energy released in the process (Q-value). The one dimensional total potential V is given by

$$V = V_c + V_s + V_l - V_0 \tag{1}$$

where V_c is the Coulomb potential as developed by Gaudin[5], V_l is the centrifugal potential and V_0 is the reference potential corresponding to the sum of self energies (Coulomb plus surface) of each fragment in the asymptotic region. With these available information the barrier penetration probability P is calculated as follows.

$$P = exp\left[\frac{-2}{\hbar}\int_{\zeta_0}^{\zeta_c}\sqrt{2\mu_{eff}[V(\zeta) - Q]}d\zeta\right] \tag{2}$$

Here the integration limits correspond to the inner and outer turning points. The decay rate is then calculated as

$$\lambda = \lambda_0 P \tag{3}$$

with λ_0 as the assault frequency and is taken as a constant equal to $10^{22}s^{-1}$. Finally the half life for the decay is obtained as

$$T_{1/2} = \frac{ln2}{\lambda} \tag{4}$$

Results and discussion

Gupta et al in 1992 using the preformed cluster model estimated $T_{1/2}$ for decay of clusters in the range alpha to ^{34}Si from ^{154,156,158}Gd. The values were found to be far beyond the present upper limit for experimental verification. However their study pointed out the possible instability of proton rich nuclei including Gd against heavy particle decays. We in the present study estimated the

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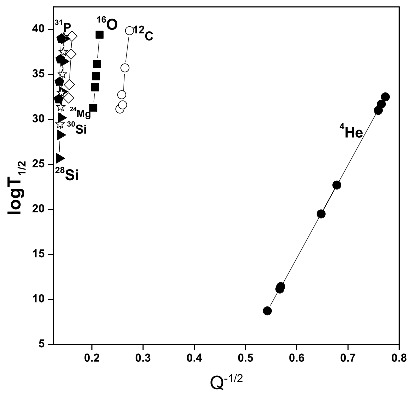

FIG. 1: Gieger-Nuttall plots for different clusters

TABLE I: Slope and intercept values of Gieger-Nuttall plots for diffrent clusters emitted from various Gd isotopes.

Cluster	Intercept Y	Slope X
^{4}He	-47.3	103.1
^{12}C	-92.5	483.2
^{16}O	-104.8	670.9
^{24}Mg	-133.0	1070.6
^{28}Si	-146.1	1264.6
^{30}Si	-146.8	1277.7
^{31}P	-152.5	1365.3

fragmentation potentials using ELDM at the touching configuration for the decay of various clusters from ^{137}Gd. This indicates the presence of minima corresponding to different clusters and this motivated us to carry out the feasibily study for the emission of various clusters such as alpha, ^{12}C, ^{16}O, ^{24}Mg, ^{28,30}Si and ^{31}P.

On plotting the estimated $\log T_{1/2}$ values against $Q^{-1/2}$ for the decay of alpha and other clusters from different parents, we got the Gieger-Nuttall plots as shown in Fig. 1. These were subjected to straight line fitting and the resulting slopes (X) and intercepts (Y) are as given in table 1.

We analysed the variation of slope and intercept of these Gieger-Nuttall plots with proton number Z_2 of the cluster and arrived at a general equation for half life time which are applicable to all clusters from various Gd isotopes. It is given as

$$log_{10}(T_{1/2}) = \frac{X(Z_2)}{\sqrt{Q}} + Y(Z_2), \quad (5)$$

where

$$X(Z_2) = -0.01902(Z_2)^3 + 0.74348(Z_2)^2 + 89.32636Z_2 + 77.9984 \quad (6)$$

and

$$Y(Z_2) = -0.03902(Z_2)^3 + 1.19725(Z_2)^2 - 18.51812Z_2 + 14.85667 \quad (7)$$

The cluster ^{28}Si from ^{137}Gd and ^{138}Gd have $\log T_{1/2}$ values 28.265 and 30.185 respectively which are below the present upper limit of measurement. Hence ^{137}Gd and ^{138}Gd can be possible candidates for cluster emission. This also emphasises the role of Sn nuclei in the decay of other trans-tin nuclei.

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