The Double Alpha Decay of Curium and Berkelium Isotopes

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Abstract

The double alpha (2α) emission from several Cm and Bk isotopes with mass number A=211 to 286 are studied within the Modified Generalized Liquid Drop Model (MGLDM) and Universal Decay Law (UDL). The half-lives for most probable 2α emission, calculated within MGLDM by using different preformation factors (P_c), are presented. The observed peak (maxima) or dip (minima)in 2α decay half-life is responsible for the stability of the parent or daughter nucleus respectively. From this study, the neutron numbers 126, 162, 172 and 184 are found to be magic and semi-magic shell closures.

Keywords: *alpha decay, double alpha decay, liquid drop model*

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1. Introduction

The alpha decay is one of the prominent decay modes of nuclei in the heavy and superheavy regions. The concurrent emission of two alpha (2α) particles from a radioactive nucleus is termed as double alpha decay. The concept of spontaneous emission of 2α particles from a nucleus was first predicted by Poenaru et al.,[1] in 1985. There have not been many studies both theoretical and experimental to understand the possibility of the emission of 2α particles, after its first prediction. Recently in 2021, Tretyak [2] studied the possibility of 2αemission from 80 naturally available nuclei. The author also reported, for the first time, the experimental $T_{1/2}$ limit for 2α emission from ^{209}Bi isotopes. By analyzing the data of Marcillac et al.,[3] to observe single α decay from ^{209}Bi, Tretyak set the experimental $T_{1/2}$limit for 2α emission from ^{209}Bi as $T_{1/2} > 2.9 \times 10^{20}$ y. Very recently we have studied the possibility of 2α decay from ^{209}Bi and the predicted half-life and it is checked with the reported experimental $T_{1/2}$limit [4, 5].

In the present work, we aim to study the possibilities of 2α emissions from several isotopes of Cm and Bk with mass number A =211 to 286 using MGLDM and well-known UDL of Qi et al.,[6] for alpha and cluster radioactivity

2. Modified Generalized Liquid Drop Model (MGLDM)

In MGLDM, the total energy for a deformed nucleus is defined as,

$$E = E_V + E_S + E_C + E_R + E_P \quad (1)$$

Here the terms E_V, E_S, E_C, E_R and E_P represent the volume, surface, Coulomb, rotational and proximity energy terms respectively. The barrier penetrability P is calculated using the following integral,

$$\mathrm{P} = \exp\left\{-\frac{2}{\hbar}\int_{R_{in}}^{R_{out}}\sqrt{2B(r)[E(r)-E(sphere)]}dr\right\} \quad (2)$$

Where R_{in} and R_{out} are the inner and outer turning points and B(r) is reduced mass.

The partial half-life is related to the decay constant λ by

$$T_{1/2} = \left(\frac{\ln 2}{\lambda}\right) = \left(\frac{\ln 2}{\nu P_C P}\right) \quad (3)$$

Here P_c is the preformation factor and the frequency of assault $\nu = 10^{20}\ \mathrm{s}^{-1}$.

2.1 Preformation factor

We consider that the 2α particle is already preborn within the parent nucleus before emission, similar to that in alpha and cluster radioactivity. The decay half-life is generally influenced by the variables used, such as Q value; cluster size; atomic number of cluster and daughter nuclei and the combination of these three variables, to compute the preformation factor. The MGLDM with different P_c values are proved its success in explaining the alpha and cluster decay can be extended to study the concept of 2α decay and the details of the preformation parameters are as follows:

$$P_c(Q) = 10^{aQ+bQ^2+c} \quad (4)$$

with a = -0.25736, b = 6.37291 x 10^{-4}, c = 3.35106

$$P_c(A_c) = 10^{aA_c+b} \quad (5)$$

with a =-0.51325 and b = 2.80787

$$P_c(Z_c Z_d) = 10^{aZ_c Z_d+b} \quad (6)$$

with a =-0.01555 and b = 3.22940

$$P_c(C) = 10^{aA_c+bZ_cZ_d+cQ+dQ^2+e} \quad (7)$$

with a = -0.5559, b = 0.028716,
c = - 0.4233358, d = 0.001143 and

e = 1.490754

In the above relations the variables, Q, A_c and $Z_c Z_d$ are the Q value, cluster size, and atomic number of cluster and daughter nucleus respectively. The value of constants in each relation are found by the method of least square regression.

3. Universal Decay Law (UDL)

The relation for UDL for cluster decay proposed by Qi and co-workers [6] is given as,

$$log_{10}(T_{1/2}) = aZ_c Z_d \sqrt{A/Q_c} + b\sqrt{AZ_c Z_d (A_d^{1/3} + A_c^{1/3})} + c, \quad (8)$$

where A_c, A_d are mass number of cluster and daughter nuclei respectively; Z_c, Z_d are proton number of cluster and daughter nuclei respectively. The constants are a = 0.3949, b = -0.3693, c = -23.7615 and $A = A_c A_d/(A_c + A_d)$.

4. Results and discussion

The 2α emission from various Cm and Bk isotopes with mass number A =211 to 286 are studied using MGLDM by incorporating different P_c values. The emitted 2α particle will tunnel through the potential barrier and then emitted from the parent nucleus. In concurrent emission of 2α particles, we can imagine both alpha particles move as a cluster and leave the nucleus after tunneling through the barrier. The energy released, i.e., the Q value of a reaction is,

$$Q = \Delta M_p - (\Delta M_d + \Delta M_c) > 0, \quad (9)$$

where ΔM_p, ΔM_d and ΔM_c are the mass excess of parent, daughter and cluster nuclei respectively. For α decay, ΔM_c=ΔM_α and for 2α decay,ΔM_c=$2 \times \Delta M_\alpha$, where ΔM_α is the mass excess of α particles. For computing Q values for the α decay and 2α decay of all parent nuclei are evaluated using the recent mass model proposed by Wang et al., [7].

Figure1, gives the plot connecting the $\log_{10}T_{1/2}$ values computed using the MGLDM with different P_c values and UDL for the 2α decay of $^{211-285}$Cm and $^{214-286}$Bk. In the case of $^{211-285}$Cm, half-life shows a dip (minimum value) at mass numbers 218, 254 and 276 corresponding to magic neutron shell closure 126, 162 and 184. In the case of double alpha decay of $^{214-286}$Bk, minimum $T_{1/2}$ is observed at mass numbers 219, 255, 265 and 277 where the daughter nuclei have magic neutron shell closure at 126, 162, 172 and 184 accordingly. When

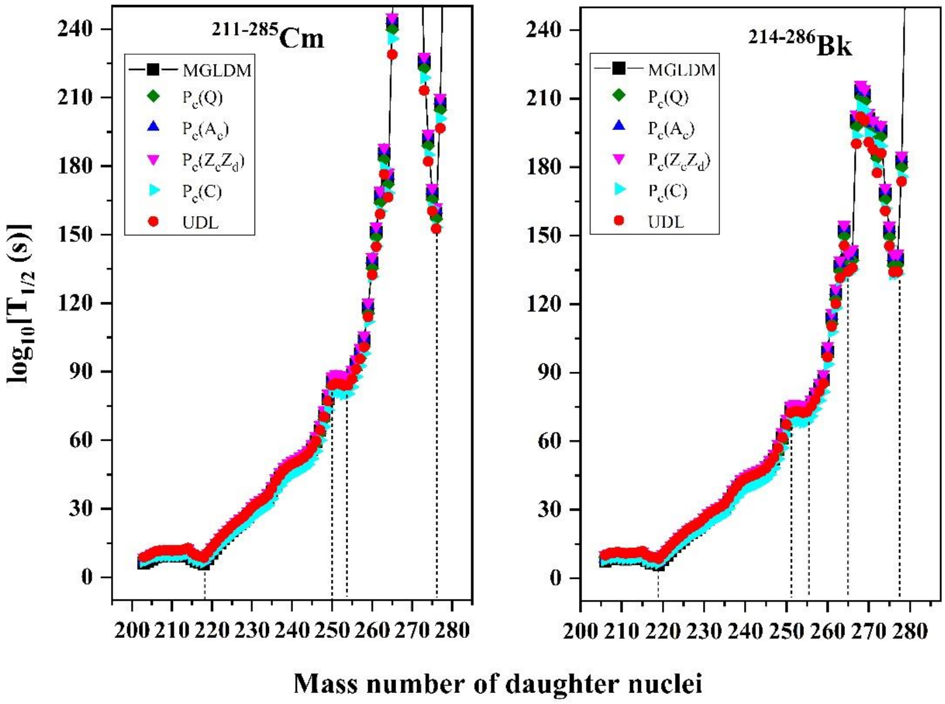

Figure 1. *The variation of logarithm of half-life with the mass number of daughter nucleus for 2α decay from $^{211-285}$Cm and $^{214-286}$Bk*

the parent nucleus has 162 neutrons, a peak appears at mass numbers 250 and 251 for Cm and Bk respectively, suggesting a maximum half-life and stability.

We can therefore draw the conclusion that for a given group of isotopes, the minimum$\log_{10}T_{1/2}$ value denotes the stability, neutron shell closure of the daughter nucleus. The peak (maximum) in $\log_{10}T_{1/2}$ value also denotes the stability, neutron shell closure of the parent nucleus.

5. Conclusions

In this work we have evaluated the 2α decay half-lives of Cm and Bk isotopes with A=211 to 286 using MGLDM and UDL. This study reveals the stability of daughter nuclei and parent nuclei which is associated with the minimum and maximum half-life respectively. The observed peak or dip at magic/semi-magic neutron numbers 126, 162, 172and 184 is the reason for the extra stability of the parent and daughter nucleus at these numbers.

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