Ground state decay of Ra and Th isotopes using Skyrme energy density formalism

Rajni[1,2],* Gudveen Sawhney [3], Manoj K Sharma[2], and Ajay Kumar Rai[1]
[1]*Department of Physics, Sardar Vallabhbhai National Institute of Technology Surat 395007, Gujarat, India*
[2]*School of Physics and Materials Science, Thapar Institute of Engineering and Technology, Patiala - 147004, Punjab, India and*
[3]*Department of Physics, University Institute of Sciences, Chandigarh University, 140413, Punjab, India*

Introduction

The first experimental signature of cluster radioactivity (CR) was given by Rose and Jones, where ^{14}C cluster was emitted from ^{223}Ra parent nucleus. After that various heavy clusters such as ^{20}O, ^{23}F, $^{22,24-26}$Ne, ^{28,30}Mg, and ^{32,34}Si have been reported in different experiments by investigating the decay of several trans-lead parent nuclei ranging from Z=87-96. Such decay modes proceed via double magic ^{208}Pb (or neighbouring nuclei). This suggests that the shell effect plays a crucial role in the cluster emission of heavy nuclei.

In past few decades, half lives of various clusters have been investigated using a different nuclear models. In the present work, we take up this study on the basis of preformed cluster model (PCM) [1] in which Skyrme energy density formalism (SEDF) [2] is applied to investigate the ground state decay of Ra and Th isotopes such as ^{222}Ra, ^{224}Ra, ^{226}Th and ^{228}Th. Within SEDF, SIII force is used to obtain the half-lives of considered parent nuclei. The calculations suggest that the considered force is able to give fair agreement with the half-lives of experimental data [3, 4].

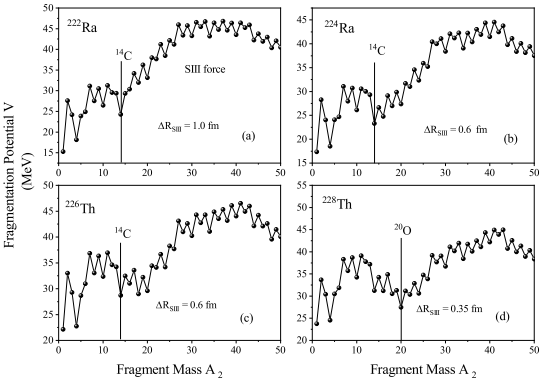

FIG. 1: Fragmentation potential of (a) ^{222}Ra (b) ^{224}Ra (c) ^{226}Th and (d) ^{228}Th parent nuclei for deformed choice of decaying fragments using SIII force. The figure is plotted at fitted values of neck-length parameter ΔR.

TABLE I: PCM calculated preformation probability P_0 and penetrability P for the most probable clusters emitted from different parents using SIII force.

Decay channel	P_0	P
^{222}Ra$\rightarrow^{14}$C+^{208}Pb	1.08×10^{-14}	4.85×10^{-20}
^{224}Ra$\rightarrow^{14}$C+^{210}Pb	1.16×10^{-13}	4.31×10^{-25}
^{226}Th$\rightarrow^{14}$C+^{212}Po	4.49×10^{-13}	4.39×10^{-25}
^{228}Th$\rightarrow^{20}$O+^{208}Pb	2.89×10^{-9}	1.11×10^{-30}

Methodology

Within Preformed Cluster Model (PCM), the decay half-life $T_{1/2}$ is defined as,

$$\lambda = \frac{\ln 2}{T_{1/2}} = P_0 \nu_0 P. \quad (1)$$

Here P_0 is the cluster (and daughter) preformation probability calculated using Schrödinger wave equation and P is the barrier penetrability obtained by using WKB approximation. ν_0 is the barrier assault fre-

*rajni.mittal1989@gmail.com

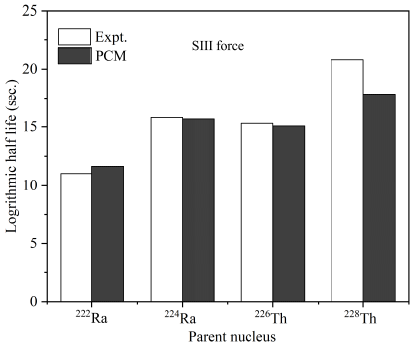

FIG. 2: PCM calculated half-life times using SIII Skyrme force for cluster decay of Ra and Th isotopes compared with experimentally available data [3, 4].

quency, which remain almost constant $\sim 10^{21}$ s^{-1} for all the heavy cluster decays studied in the present work.

The structure information of the decaying nucleus is contained in P_0 via the fragmentation potential $V_R(\eta)$ calculated as

$$V_R(\eta) = -\sum_{i=1}^{2}[B_i(A_i, Z_i)] + V_C(R, Z_i, \beta_{\lambda i}, \theta_i) + V_N(R, A_i, \beta_{\lambda i}, \theta_i) \quad (2)$$

Here V_C and V_N are respectively the Coulomb and nuclear potentials for deformed and oriented nuclei. B_i are the binding energies of decaying fragments. In the present work V_N is obtained by using the Skyrme Energy Density Formalism (SEDF).

Calculations and Results

Fig.1 shows the fragmentation potential of ^{222,224}Ra and ^{226,228}Th parents, plotted to identify the most probable cluster and daughter in the exit channel using SIII force. One may observe from the figure that the minima in the fragmentation plot of considered parents signify the emission of most favorable clusters (pointed with solid vertical line) emitting from the respective parents. For ^{222,224}Ra and ^{226}Th emitters, corresponding cluster is ^{14}C, and ^{20}O is the most favorable cluster in case of ^{228}Th. In the previous analysis of PCM [5], similar result was obtained with the use of different proximity potentials and now the present work is extended in reference to the Skyrme energy density formalism. Note that, the choice of most probable cluster for all parents also indicate the role of shell closure effect as the daughter nucleus corresponds to these parent nuclei belong to doubly magic ^{208}Pb or its neighboring isotope, as shown in Table 1.

Further, the preformation probability P_0 and penetrability P of considered decay channel is calculated for considered parents and reported in Table 1. It is relevant to mention here that the P_0 and P are obtained at an optimized neck-length parameter 'ΔR'. The values of preformation probability and penetrability are then used to obtain the decay half-lives (see Eq.(1)). Fig.2 depicts the variation of PCM calculated half-lives using SIII force and comparison is made with experimentally available data [3, 4]. It is evident from the figure that SIII force within PCM provides fair agreement of all half-lives with experimentally observed data.

Acknowledgments

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