Exploring New Isotopes of Californium

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Introduction

Exploring new isotopes of Californium (Cf) is an exciting area of nuclear physics, particularly due to the unique properties of Californium, which is a heavy, radioactive element. This element was discovered by Thompson et al. [1], just two months after the preparation and identification of the first isotope of Berkelium, element 97. Ghiorso [2] later provided an account and reflections on the early work surrounding the discovery of Californium. Transactinide isotopes are synthesized via nuclear reactions, as neutron capture is no longer feasible [3]. From Rutherfordium (Z=104) to Oganesson (Z=118), discovery required heavy ion beams, advanced technology, and detectors.

Manjunatha et al., [4] studied the competition between different decay modes such as alpha, beta, proton and spontaneous fission in the isotopes of actinide nuclei. Sowmya et al. [5] predicted potential isotopes for Z = 116 by analyzing the competition between various decay modes, including binary fission, ternary fission, cluster radioactivity, and alpha decay. Hence, from the detail investigations, we were motivated to investigate new isotopes of Californium. These studies highlight the importance of understanding decay dynamics in heavy elements. Motivated by their findings, we were inspired to investigate new isotopes of Californium by studying competition between different decay modes such as alpha, beta, proton-decay, spontaneous fission. Alpha and proton decay half-lives are evaluated using deformation dependent Coulomb and proximity potential model. However, $\beta^{\pm}$-decay and spontaneous fission half-lives were evaluated using semi-empirical formulae available in the literature.

Theoretical Framework:

The alpha and proton-nucleus total potential is expressed as

$$V = V_C + V_P \quad (1)$$

The Coulomb interaction (V_C)potential is given by

$$V_c = \frac{Z_1 Z_2 e^2}{r}\left[1 + \frac{3R^2}{5r^2}\beta_2 Y_{20}(\theta) + \frac{3R^4}{9r^4}\beta_4 Y_{40}\right] \quad (2)$$

here Z_1 and Z_2 are the atomic numbers of alpha/proton and daughter nuclei respectively. The term 'r' and R are the separation distance, and radius of the nuclei, β is quadrupole deformation parameter and $Y_{20}(\theta)$ / $Y_{40}(\theta)$ is the spherical hormanic function. Proximity potential is evaluated as follows;

$$V_P = 4\pi\gamma b\left[\frac{C_1 C_2}{C_1 + C_2}\right]\varphi \quad (3)$$

The penetration probability and half-lives are evaluated as explained in detail in literature [5]. The beta decay and spontaneous fission half-lives are evaluated using semi-empirical relations [4]. The spontaneous fission half-lives are evaluated using the following equation.

$$\log T_{SF}(s) = 1146.44 - 75.3153\left(\frac{Z^2}{A}\right) + 1.63792\left(\frac{Z^2}{A}\right)^2 - 0.0119827\left(\frac{Z^2}{A}\right)^3 + B_f\left(7.23613 - 0.0947022\, Z^2/A\right) + \begin{cases} 0, & Z \text{ and } N \text{ are even}, \\ 1.53897, & A \text{ is odd}, \\ 0.80822, & Z \text{ and } N \text{ are odd}, \end{cases} \quad (4)$$

Here B_f is the fission barrier , Z and N are the atomic number and neutron number of parent nuclei respectively.

Results and Discussion:

The alpha, and proton decay half-lives are studied in the isotopes of Californium (Cf) using Coulomb and proximity potential model. However, $\beta^{\pm}$-decay and spontaneous fission half-lives are evaluated using semi-empirical relations. If the Q-value of the reaction in alpha, beta, and proton-decay is positive, then the decay is energetically feasible [6]. The mass excess values in order to evaluate Q-valuesare taken by recent mass excess data available in literature [7]. Figure 1. represents the variation of logarithmic half-lives as a function of mass number of parent nuclei for different decay modes. The alpha-decay and β^+-decay increases with increase mass number and β^--decay half-lives gradually decreases. From this comparison, ^{235}Cf is identified as β^+-emitter. Hence, further we investigated decay chains of the newly identified isotope of Californium.

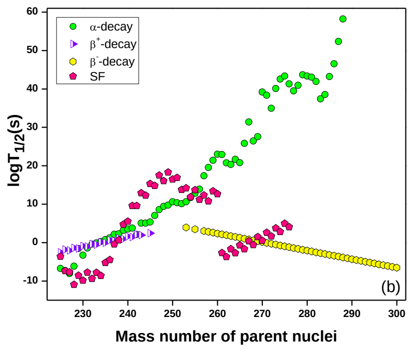

Figure-1: A plot of logarithmic half-lives as a function of mass number of parent nuclei for alpha, beta, proton decay, and spontaneous fission.

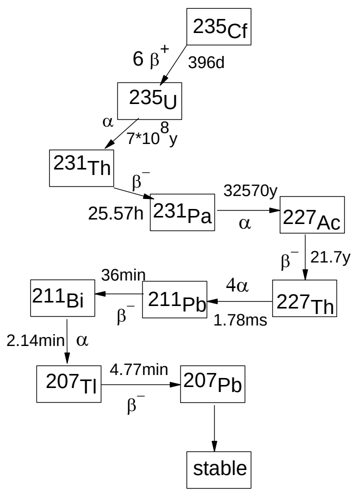

Figure-2: Decay chains of ^{235}Cf nuclei.

Figure-2 shows decay chains of ^{235}Cf nuclei. ^{235}Cf is unstable against β^+-decay, hence it converts to ^{235}U followed by 6β^+-emitters. Further, ^{235}U is unstable and it becomes ^{231}Th by emitting α-decay. Similarly, we have shown the consistent decay chains, and finally stable ^{207}Pb nuclei is formed followed by β^--decay. Hence, these newly identified isotopes along with half-lives in decay chains are helpful for further avenues in identification of new isotopes.

Conclusions:

We investigated different decay modes such as alpha, beta, proton-decay, spontaneous fission in the isotopes of Californium using Coulomb and proximity potential model and semi-empirical formula available in literature. By comparing these half-lives, ^{235}Cf is identified as β^+-emitter. Further, we investigated the decay chains of ^{235}Cf nuclei. ^{235}Cf nuclei undergoes consistent β^+-decay, followed by α-decay and β^--decay. A stable ^{207}Pb nuclei is formed followed by β^--decay. These consistent decay chains, along with half-life data, provide valuable insights for identifying new isotopes and exploring their decay properties.

References:

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