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Stability of $^{248-254}$Cf isotopes against alpha and cluster radioactivity

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HIGHLIGHTS

- $^{248-254}$Cf parents are stable against light clusters (except alpha particles) and are unstable against heavy clusters (^{46}Ar, ^{48,50}Ca etc.).
- For the case of heavy cluster emissions the daughter nuclei are doubly magic ^{208}Pb or neighbouring one.
- The alpha decay half lives are in agreement with experimental data.
- The cluster decay half lives decrease with the inclusion of quadrupole deformation.

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ABSTRACT

Stability of $^{248-254}$Cf nuclei against alpha and cluster emissions is studied within our Coulomb and proximity potential model (CPPM). It is found that these nuclei are stable against light clusters (except alpha particles) and unstable against heavy cluster ($A_2 \geq 40$) emissions. For heavy cluster emissions the daughter nuclei lead to doubly magic ^{208}Pb or the neighbouring one. The effects of quadrupole and hexadecapole deformations of parent nuclei, daughter nuclei and emitted cluster on half lives are also studied. The computed alpha decay half life values (including quadrupole deformation β_2) are in close agreement with experimental data. Inclusion of quadrupole deformation reduces the height and width of the barrier (increases the barrier penetrability) and hence half life decreases.

1. Introduction

Cluster radioactivity is the spontaneous emission of particle heavier than alpha particle predicted by Sandulescu et al. [1] in 1980, after four years Rose and Jones [2] confirmed this phenomenon in

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the emission of ^{14}C from ^{223}Ra isotope. After the observation of cluster radioactivity, lots of efforts have been done on both experimental and theoretical fronts for understanding the physics of cluster radioactivity. In literature there existed old fission data of Jaffey and Hirsch [3] for ^{24}Ne decay of ^{232}U, which indicates that this phenomenon was already observed in 1951, but the authors did not distinguish it from the spontaneous fission process. In a very recent experiment, Bonetti et al. [4] have confirmed that the emission of ^{24}Ne from ^{232}U, seen in 1951 could not be due to spontaneous fission since the then-observed cluster decay constant is larger than by an order of magnitude 10^2 than their presently measured upper limiting value of spontaneous fission decay constant. At present about 24 modes of cluster decay from about 20 parent nuclei emitting clusters ranging from carbon to silicon are confirmed so far. For e.g. ^{14}C from ^{221}Fr, $^{221-226}$Ra and ^{226}Th, ^{20}O from ^{228}Th, ^{24,26}Ne from ^{230,232}Th and ^{232,234}U, ^{28,30}Mg from ^{238}Pu, ^{32,34}Si from ^{238}Pu and ^{241}Am etc. are observed.

The present study points out the role of deformations on half lives in the cluster decay process. Since the beginning of cluster radioactivity, it was recognized to be a consequence of the shell closure of one or both the fragments because of its cold nature; i.e. the low excitation energy involved in the process. An opened problem in the study of cluster radioactivity is represented by the question of the existence of only the spherical or both the spherical and deformed closed shells. It is relevant to mention here that all the parents ^{228,230}Th, ^{232,234,238}U, ^{236,238}Pu and ^{242}Cm and their respective emitted clusters ^{20}O, ^{24}Ne and ^{28,30}Mg considered here are deformed, except for ^{25,26}Ne and ^{32,34}Si which are spherical or nearly spherical. Also all parent nuclei are prolate deformed whereas clusters ^{24}Ne, ^{30}Mg are oblate deformed and ^{20}O, ^{28}Mg are prolate deformed.

The effects of deformation in cluster decay half life are studied by many authors using different theoretical models. The theoretical study of deformation effects on the WKB penetrabilities have been carried out by Sandulescu et al. [5,6] using the double folded Michigan-3 Yukawa (M3Y) potential for a spherical daughter and a quadrupole deformed emitted cluster. In 1986 Pik Pichak [7,8] studied the effect of ground state deformation of parent and daughter on half life treating emitted cluster as spherical. One year later Shi and Swiatecki [9] studied the effect of deformation of parent, daughter and shell attenuation on half life time treating emitted cluster as spherical in shape. Kumar et al. [10] studied the effect of deformation of cluster and daughter nuclei and also the role of neck formation in overlap region. Shanmugam et al. [11] put forward cubic plus Yukawa plus exponential model (CYEM) which uses Coulomb and Yukawa plus exponential potential as interacting barrier for separated fragments and cubic potential for the overlap region. The authors also studied [12] the role of deformation of parent and daughter nuclei on half life time.

Californium does not occur naturally but is produced artificially in nuclear reactors and particle accelerators. Californium was first produced [13–15] in 1950 in a cyclotron at the University of California at Berkeley by bombarding ^{242}Cm with helium ions. The half lives of californium isotopes range from 0.91 s to 900 years. All the $^{248-254}$Cf isotopes decay by emitting an alpha particle but ^{248}Cf also decay by spontaneous fission, a process in which the atom self-disintegrates into two smaller atoms accompanied by a burst of neutrons and a release of energy and nearly about 3% of the ^{252}Cf decays by spontaneous fission. One of the interesting facts for the study of californium isotopes is that some of these isotopes show both spontaneous binary and ternary fission [16–19].

Within the Coulomb and proximity potential model (CPPM) proposed by one of us (KPS), we have studied [20] the cold valleys in the radioactive decay of $^{248-254}$Cf isotopes and the computed alpha decay half life time values were found to be in agreement with the experimental data. In the present paper we have investigated all the possible cluster emissions from the $^{248-254}$Cf parents by including the quadrupole and hexadecapole deformations of the decaying parent nucleus along with that of emitted cluster and corresponding daughter nucleus in the ground state. The details of the model are given in Section 2. The results and discussion are given in Section 3 and the conclusion is given in Section 4.

2. The Coulomb and proximity potential model (CPPM)

In Coulomb and proximity potential model the potential energy barrier is taken as the sum of Coulomb potential, proximity potential and centrifugal potential for the touching configuration and for the separated fragments. For the pre-scission (overlap) region, simple power law interpolation as