CLUSTER RADIOACTIVITY IN ^{114}Ba IN THE HFB THEORY*

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(Received January 11, 2011)

Cluster radioactivity in ^{114}Ba is described as a spontaneous fission with a large mass asymmetry within the self-consistent HFB theory. A new fission valley with large octupole deformation is found in the potential energy surface. The fragment mass asymmetry of this fission mode corresponds to the expected one in cluster radioactivity with the emission of ^{16}O predicted with a very long half-life.

DOI:10.5506/APhysPolB.42.477
PACS numbers: 21.60.Gx, 25.85.Ca, 27.60.+j

1. Introduction

Cluster radioactivity (CR) discovered by Rose and Jones [1] was observed in 19 actinides. This is an exotic process in which a light nucleus (^{14}C up to ^{34}Si) is emitted and a nucleus from the region of ^{208}Pb constitutes the heavy mass residue. Since a doubly-magic structure of the heavy fragment is a necessary condition for CR, such a decay may be also associated with the doubly-magic ^{100}Sn. The shortest CR half-lives in actinides are obtained for the emission of a light ^{14}C cluster. This implies that the best candidate as emitter from the ^{100}Sn region is ^{114}Ba. Experimental investigations of cluster decay in this isotope have been carried out, but no evidence was found for CR and only a lower limit for the half-life $t_{1/2}$ could be determined. Oganessian *et al.* [2] found $t_{1/2} > 10^3$ s, whereas the value found by Guglielmetti *et al.* [3,4] is larger $t_{1/2} > 1.2 \times 10^4$ s.

We showed in a fully microscopic approach [5,6] that CR can be described as a very asymmetric spontaneous fission process. The potential energy surfaces were determined as function of quadrupole and octupole moments within the framework of the Hartree–Fock–Bogoliubov model with the D1S

* Presented at the Zakopane Conference on Nuclear Physics "Extremes of the Nuclear Landscape", August 30–September 5, 2010, Zakopane, Poland.

Gogny force [7]. New fission valleys in the energy surfaces with fragment mass asymmetry characteristic for CR were found. The experimental half-lives of CR in actinides were reproduced with good accuracy. The same model can be applied to lighter systems. In this contribution we present the results of our investigations of CR in ^{114}Ba.

2. Results

In Fig. 1 the potential energy surface of ^{114}Ba is shown as function of quadrupole and octupole moments. There are two fission paths on that surface, marked with dashed lines. The first one, along $Q_3 = 0$, leads to mass symmetric fission. The corresponding barrier is however too large to make spontaneous fission possible. The second fission path starts in the ground state at ($Q_2 = 4\,\mathrm{b}$, $Q_3 = 0\,\mathrm{b}^{3/2}$) and goes through the saddle point at ($Q_2 = 16\,\mathrm{b}$, $Q_3 = 12\,\mathrm{b}^{3/2}$). The nucleus takes shapes with octupole deformation along this path and reproduces mass asymmetry of CR. The asymmetric potential energy barrier is very high and reaches 23 MeV, which corresponds to a typical value of a CR barrier in the actinide region. The neck rupture takes place at the saddle point which means that the scission point is localized on top of the barrier. While the Coulomb interaction between fragments decreases with the distance between fragments the energy decreases as well. This can be clearly seen in Fig. 2 where the potential energy along the cluster emission path is plotted as function of the octupole moment. Due to the insufficient size of the basis used in the calculations at huge deformations, the potential energy of the nucleus at large Q_3 is not properly minimized. Therefore the classical formula for the Coulomb energy is used to determine the fission barrier beyond the scission point. The Coulomb energy, marked by a dashed line in Fig. 2, perfectly coincides with the self-consistent energy close to the saddle point and deviates from it significantly for $Q_3 > 70\,\mathrm{b}^{3/2}$.

In Fig. 3 contour-plots of the nuclear density distribution along the CR fission path are shown. The molecular structure of the deformed nucleus can be seen at very low octupole deformation $Q_3 > 4\,\mathrm{b}^{3/2}$. The neck becomes thinner and nuclear density in the neck decreases gradually with increasing deformation up to the saddle point at $Q_3 = 12\,\mathrm{b}^{3/2}$. Finally at $Q_3 = 14\,\mathrm{b}^{3/2}$ the neck is ruptured and two fragments are observed. A further increase of the deformation of the system is obtained with increasing distance between the fragments. The light cluster ^{16}O and the heavy mass residue ^{98}Cd are created at the scission point. The discrepancy of two protons from expected ^{14}C and ^{100}Sn fragments is noticed. Due to strong shell effects the doubly-magic structure of the cluster is energetically more favourable than the doubly-magic heavy fragment. Similarly nuclei in the vicinity of ^{208}Pb are also often observed as one of the products of the CR decay of actinides.

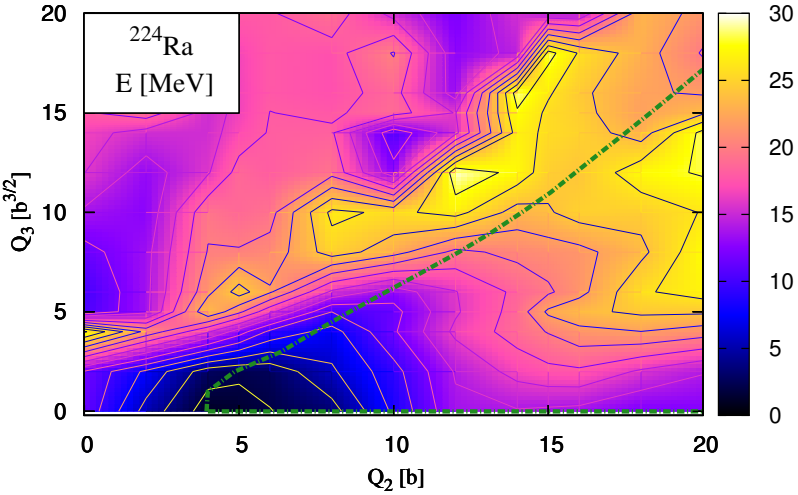


Fig. 1. Potential energy surface in ^{114}Ba as function of quadrupole moment Q_2 and octupole moment Q_3. Lines of constant energy are plotted every 2 MeV. Bold dash-dotted lines are plotted along the two different fission paths.

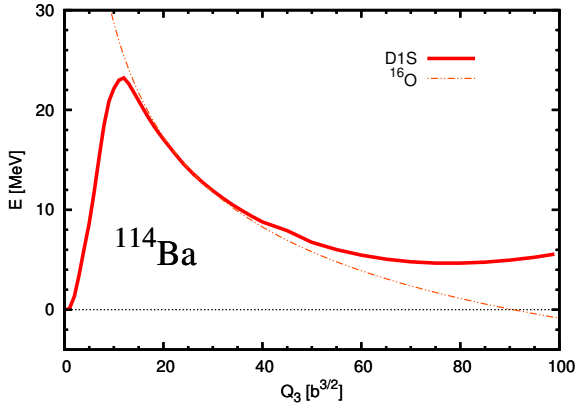


Fig. 2. Asymmetric fission barrier in ^{114}Ba as function of the octupole moment Q_3. The thin dashed line corresponds to the classical Coulomb energy of two fragments ^{16}O and ^{98}Cd.

The half-life of CR in ^{114}Ba has been calculated in the WKB approximation [7]. The octupole moment has been taken as leading coordinate in an action integral [5, 6]. Microscopic values of zero-point energy along the whole fission path have been used to calculate the action integral. A half-life of $t_{1/2} = 4.7 \times 10^9$ s has been obtained. This value fits experimental data, being much larger than the experimental lower limit.

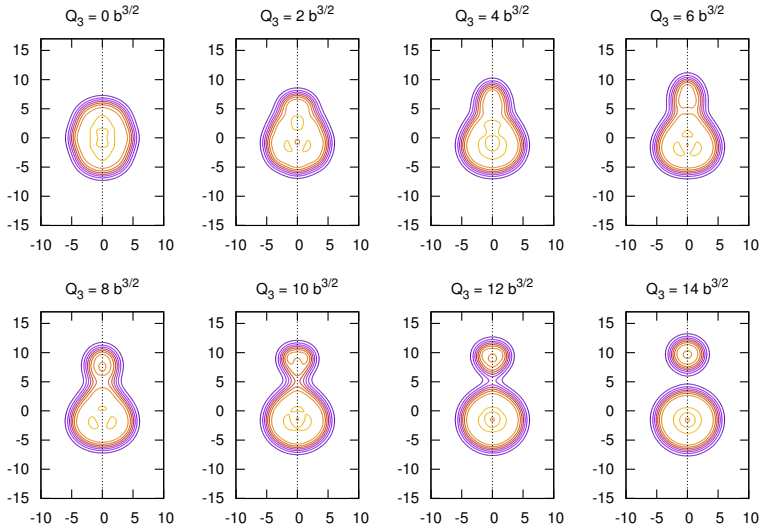


Fig. 3. Evolution of the shape of ^{114}Ba along the asymmetric fission path. Equidensity lines are plotted every 0.02 fm^{-3}.

3. Conclusions

A new valley in the potential energy surface of ^{114}Ba leading to fission with two fragments ^{16}O and ^{98}Cd is discovered. The decay products correspond to the cluster radioactivity predicted in this nucleus. The fission barrier for this decay is 23 MeV high. The nucleus has octupole deformation along the whole fission path. A large half-life for cluster radioactivity $t_{1/2} = 4.7 \times 10^9$ s is found which is consistent with experimental data.

This work is partially supported by Grant No. N N202 231137 from the Ministry of Science and Higher Education, Poland. The author is grateful to L.M. Robledo for helpful discussion at all stages of this work.

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