Preformation probabilities of two proton emitters

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Introduction

Near proton drip line one/two proton radioactivity occurs in neutron deficient or proton rich nuclei. One proton radioactivity of several nuclei containing odd-proton has been studied extensively both theoretically and experimentally. The two proton radioactivity though experimentally confirmed for some nuclei such as ^{45}Fe, ^{48}Ni, ^{54}Zn and ^{67}Kr but still requires further experimental confirmation of promising cases such as ^{19}Mg, ^{30}Ar, ^{34}Ca, ^{62}Se, ^{66}Kr and ^{71}Sr which has been predicted theoretically by different models.

In this work, we employ the Cluster Core Model [1] developed for the studies of neutron and proton halo structure of neutron-rich and proton rich nuclei, to study the two proton emitters. In addition to the potential energy surface calculation, we also present for the first time the preformation probability of two proton emitters.

The potential energy is calculated as

$$V(\eta) = -\sum_{i=1}^{2} B_i(A_i, Z_i) + \frac{Z_1 Z_2 e^2}{R} + V_p$$

at fixed R, the touching configuration radius $R = R_1 + R_2$. This model is worked out in terms of the collective coordinates of mass asymmetry $\eta = (A_1 - A_2)/(A_1 + A_2)$ and relative separation R. For radius, we have the standard form, $R_i = r_0 A_i^{\frac{1}{3}}$ fm. Here r_0 is the nuclear radius constant and $A_i = A_1, A_2$ are the mass numbers of core and cluster.

Here $B(A_i, Z_i)$ are the experimental binding energies or mass excess. For neutron clusters, the mass excess is taken as $x\Delta m_n$, where x is the number of neutrons and Δm_n=8.0713 MeV. For proton clusters, mass excess is taken as $x\Delta m_p - a_c A_2^{5/3}$, where x is the number of protons and Δm_p=7.2880 MeV and a_c = 0.7053 MeV. In the fragment breakup, we consider neutron cluster(s) as well as proton clusters.

The second term is the Coulomb energy where $Z_i = Z_1, Z_2$ are the charge numbers of the core and cluster respectively and $e^2 = 1.44$ MeVfm. The third term V_p is the nuclear proximity potential and for spherical fragments it is given as

$$V_p = 4\pi \bar{R} \gamma b \Phi(\xi)$$

Here $\bar{R}$ is the mean curvature radius of the core and cluster, characterizing the gap, which for spherical nuclei is given by

$$\bar{R} = \frac{R_1 R_2}{R_1 + R_2}$$

and γ is the specific nuclear surface tension, b is the diffuseness of the nuclear surface, $\Phi(\xi)$ is the universal function which depends only on the distance between two nuclei and is independent of the atomic numbers of the two nuclei.

In this model, the potential energies are calculated for all possible cluster-core configurations which helps to find the proton(s) cluster+core configuration with a minimum potential energy.

The preformation probability P_0 is obtained by solving Schrödinger equation at fixed R,

$$\left[-\frac{\hbar^2}{2\sqrt{B_{\eta\eta}}} \frac{\partial}{\partial \eta} \frac{1}{\sqrt{B_{\eta\eta}}} \frac{\partial}{\partial \eta} + V(\eta) \right] \psi^{\nu}(\eta) = E_{\eta}^{\nu} \psi^{\nu}(\eta)$$

The Eigen-solutions of the above equation give the preformation probability for each fragmentation (A_2, A_1), as

$$P_0(A_i) = |\psi(\eta(A_i))|^2 \sqrt{B_{\eta\eta}(\eta)} \left(\frac{2}{A} \right)$$

where $B_{\eta\eta}(\eta)$, the mass parameters representing the kinetic energy part, are the smooth classical hydrodynamical mass parameters.

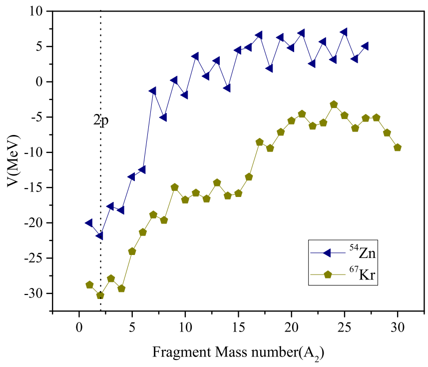

FIG. 1: The fragmentation potentials $V(\eta)$ for ^{54}Zn and ^{67}Kr.

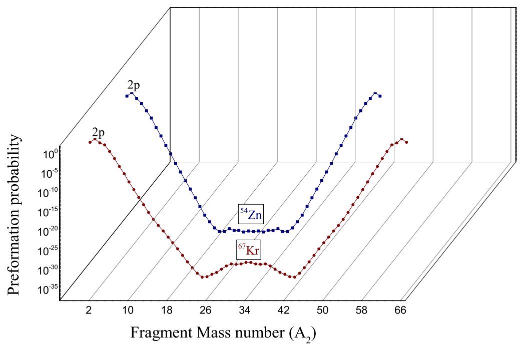

FIG. 2: The same as for Fig. 1, but for the formation yields, the cluster preformation probability.

Results and Discussions

In the present work two proton radioactivity in ^{54}Zn and ^{67}Kr are studied. Both nuclei are experimentally established [2, 3]. Blank *et al* investigated the two proton radioactivity of ^{54}Zn by measuring the *p-p* angular correlation and energy of the individual protons. Goigoux *et al* observed the 2p emission of ^{67}Kr by measuring the decay energy and compared with theoretical Q value predictions.

Fig. 1 shows the results of fragmentation potentials for the ^{54}Zn and ^{67}Kr. The deepest minimum in the potential energy surfaces clearly occurs at the 2p+core configuration. The minimum in the PES means a most probable proton-cluster+core configuration for the nucleus which agrees with the experimental result.

The preformation probability of the both the nuclei corresponding to the potential energies presented in Fig.1 are plotted in Fig.2. The results clearly indicates the preference of the 2p-cluster.

The concept is extended for the studies of all the experimentally established and theoretically proposed 2p-decay proton-rich nuclei, such as ^{19}Mg, ^{45}Fe, ^{48}Ni, ^{54}Zn, ^{34}Ca, ^{66}Kr, ^{30}Ar, ^{71}Sr, ^{62}Se, ^{67}Kr in [4].In addition to PES and preformation probability, the Q values corresponding to 1p, 2p, 4p and ^{4}He clusters for all these nuclei are also studied which again indicates the possibility of 2p cluster+core combination.

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