Studies on the existence of 1p halo isotopes via cluster decay of nuclei in super heavy region

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Introduction

A threshold effect arising from the weak binding of the valence nucleons is referred as nuclear halos [1]. The study of such nuclear halos is the most interesting fields of modern nuclear Physics. Among the two types of halo nuclei, proton halo and neutron halo, our area of interest is on the study of the structure and properties of proton halo nuclei. They were discovered recently and have attracted a lot of attention in the recent times. Proton halo states have been found in the light proton rich nuclei close to the proton drip line. They are difficult to study experimentally because of their feeble nature and the often small production cross sections. Only three or four cases are experimentally observed [2,3], which include 1p halo nuclei ^{8}B, ^{11}N, and ^{17}F; and 2p halo nuclei ^{17}Ne.

We selected some of the experimentally observed or theoretically predicted cases of proton halo nuclei, ^{8}B, ^{17}F, ^{27,28}P and identified their one proton halo structure from the separation energy findings. Further, we have compared the decay probability of ^{8}B nucleus when it is treated as a cluster and as a halo. The decay possibilities of all the selected proton halo nuclei from the various parent nuclei in the superheavy region also included in our study.

The model

1p and 2p Separation energy for any nuclei can be calculated as

$S(p) = -\Delta M(A, Z) + \Delta M(A-1, Z-1) + \Delta M_H$

$S(2p) = -\Delta M(A, Z) + \Delta M(A-2, Z-2) + 2\Delta M_H$

$\Delta M(A, Z)$, ΔM_H, $\Delta M(A-1, Z-1)$, $\Delta M(A-2, Z-2)$ are the mass excess of the parent nuclei, proton, daughter nuclei produced in the one proton and 2 proton radioactivity respectively.

If Z_1 and Z_2 are the atomic numbers of daughter and emitted cluster, the interacting potential barrier for a parent nucleus exhibiting exotic decay is given by

$$V = Z_1 Z_2 e^2/r + V_p(z) + \frac{\hbar^2 l(l+1)}{2\mu r^2} \quad \text{for } Z > 0 \qquad (1)$$

where 'r' is the distance between fragment centers, l the angular momentum, μ the reduced mass and Vp is the proximity potential

The barrier penetrably P is given as:

$$P = \exp\{-\frac{2}{\hbar}\int_a^b \sqrt{2\mu(V-Q)}dz\} \qquad (2)$$

The turning points 'a' and 'b' are given by $V(a) = V(b) = Q$, where Q is the energy released. The half life time is given by

$$T_{1/2} = \ln 2/\nu P. \qquad (3)$$

Where, $\nu = 2E_v/h$, represent the number of assaults on the barrier per second and E_v, the empirical zero point vibration energy.

Results and Discussions

In this section, we present the numerical results obtained from the half- life calculations using CPPM for the emission of 1p halo nuclei from various superheavy isotopes. The 1p halo structure can be identified from the separation energy calculations. If S(p) < S(2p), the nuclei will have 1p halo like structure, otherwise they will have 2p halo like structure

Halo nuclei	S(1p)(keV)	S(2p)(keV)
^{8}B	136.371	5743.220
^{17}F	600.269	12727.68
^{27}P	869.950	6383.970
^{28}P	2052.20	9515.500

Table 1. 1p and 2p separation energies of various proton halo nuclei.

1p and 2p separation energies of the selected nuclei are included in table 1. All the nuclei in this table are belonging to the 1p halo structure because of its low S(p) than S(2p).

The radius of the halo nuclei doesn't follow the relation $R=R_0A^{1/3}$. For example, in the case of ^{8}B, the radius is 2.2fm when it is treated as a normal cluster and the ^{8}B halo radius is 2.38fm[5]. Decay of all the selected 1p halo nuclei from the superheavy parents (Z=103-114) has studied from the calculation of the decay half- life using CPPM. Fig. 1 shows the comparison of computed half- lives for the emission of ^{8}B from the superheavy isotopes by treating them halo nuclei as well as normal cluster. It is found from the plots that the half-life for halo nuclei emission is lesser than that for cluster emission. Hence halo nuclei emission is more probable. It is also obvious from the plot that there is a dip in half life at N=126 and 138. We would like to mention that a peak in the plot of half- life shows the shell closure of parent nuclei and the dip in the half- life shows the shell closure effect of daughter nuclei. Hence the dips in this plot indicate the neutron shell closure of the daughter nuclei at N=126 and 138.

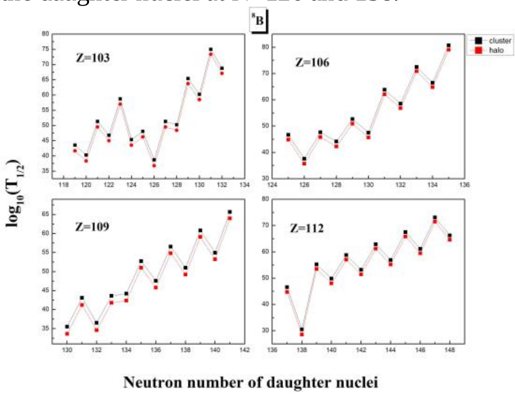

Fig. 1 Comparison of half- life for the emission of ^{8}B as a cluster and proton halo from the superheavy parent nuclei with Z=103,106,109,112

Figures 2 and 3 represent the plots of computed half- life for the emission of 1p halo nuclei such as ^{8}B, ^{17}F, ^{27,28}P from the superheavy parents with Z ranging from 103 to 114. It is found from the plot that the computed half-lives of many of the proton halo decays are well within the experimental limits (10^{30}s) of measurement. Hence, we presume that these halo and daughter combinations are probable for the formation of corresponding superheavy parents. It is also found from the plots that there are dips in the half lives at N = 126, 132, 138 and 142. This indicates the neutron shell closures of the daughter nuclei at N = 126, 132, 138 and 142. In many of the research papers predicts that the sub magic neutron shell closure occurs at N=132,138 and 142.

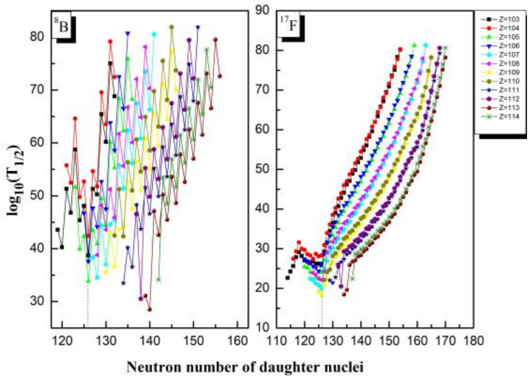

Fig. 2 Plot of $\log_{10}T_{1/2}$ versus neutron number of the daughter nuclei from Z=103-114 for the decay of ^{8}B, ^{17}F.

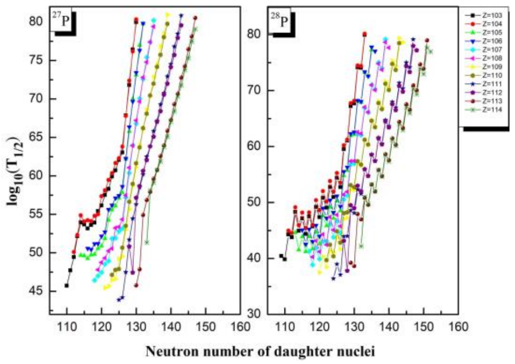

Fig. 3 Plot of $\log_{10}T_{1/2}$ versus neutron number of the daughter nuclei from Z=103-114 for the decay of ^{27,28}P.

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