Nuclei Near and Far From $\beta$-Stability Line

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Received: March 09, 2015 | Revised: March 17, 2015 | Accepted: April 11, 2015

Published online: August 03, 2015
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Abstract: Proton to neutron ratio around $\beta$-stability line presents an open challenge to the nuclear physicists. The prominent milestone in this regard is the discovery of the super heavy elements, nuclear halos in the lightest neutron-rich nuclei, experimental mapping of the nuclear shell structure near and far from stability. In this present paper, the behavior of the p- and n- halo nuclei near the $\beta$-stability line are discussed considering the variation of radius with respect to the mass number and N~Z for different nuclei. Our aim is to study the nuclear properties through neutron and proton skin. The isospin symmetry breaking is for heavy halo nuclei of strong interest.

Keywords: Neutron and proton drip line nuclei; $\beta$ stability line; n- and p- skin

1. INTRODUCTION

Nuclei having very different N/Z ratio compared to stable nuclei with the same A, large radial cut-off, high momentum distribution are generally known as drip-line nuclei. The magic nuclei having N = Z appear near the $\beta$-stability line for which $v(r) \sim r$ curve is symmetric. For proton drip-line nuclei, $v(r) \sim r$ is deeper for n- than p-halo in the medium heavy nuclei.

By choosing Wood-Saxon potential it is observed that nuclei with $l = 2$ higher orbital angular momentum lying deep are more stable compared to the $l = 0$ state. It appears for the nuclei having mass range A~ 20 – 40. Considering the Schrodinger’s equation in radial form for a finite well potential in the mass range A~ 200 – 220 nuclei having shell structure level $^2s_{1/2}$, $^1d_{3/2}$, $^1d_{5/2}$ are seen to be strongly bound and nuclei having shell structure $^1d_{3/2}$, $^2s_{1/2}$, $^1d_{5/2}$ are stable sd – shell nuclei in the mass range A~20 – 40.

The nuclei such as $^{40}_{12}$Mg, $^{42}_{13}$Al$^{28}$, $^{44}_{14}$Si$^{30}$ and their isotopes are the recently found neutron drip line nuclei. Since N > Z they occur near the $\beta^-$ - stability zone. More the columbic force between the 1n, 2n…. and the core these unstable nuclei can come closer to the $\beta^-$ - stability line and become more stable.
The proton drip line nuclei which are against the proton emission are approximately known up to Pb region. Proton drip line nuclei lie much closer to the $\beta$- stability line than the neutron drip line due to the higher columbic barrier.

The Schrodinger equation for radial wave function is written as

$$\left\{ \frac{d^2}{dr^2} - \frac{l(l+1)}{r^2} + \frac{2m}{\hbar^2} \left( \varepsilon_{nj} - V(r) - V_o(r) \right) \right\} R_{nj}(r) = 0$$

(1)

Centrifugal potential:

$$\frac{\hbar^2 l(l+1)}{2mr^2}$$

Wood-Saxon potential:

$$-\nu \frac{1}{1 + \exp \left( \frac{r-R}{a} \right)}$$

The barrier height of the potentials [Centrifugal+ Wood-Saxon] $\alpha \frac{\ell(\ell+1)}{r^2}$

$$r \sim r_c A^{1/3}$$

Eq. (1) will be solved for neutrons with the boundary conditions.

At $r = 0$, $R_\ell(r) = 0$

For large value of $r$, $V(r) = 0$

For $\varepsilon_\ell < 0$, $R_\ell(r) \propto \arctan(\alpha r)$

For $\varepsilon_\ell > 0$, $R_\ell(r) \propto \cos(\delta_\ell kr_\ell)(kr) - \sin(\delta_\ell kr_\ell)(kr)$

where $k^2 = \frac{2m\varepsilon_\ell}{\hbar^2}$, $\delta_\ell =$ Phase shift

For a given potential and energy Eigen values there are several solutions of the Eigen phases. The number of Eigen phases for a given potential and a given energy values is equal to that of the different Eigen states with different $(l, j)$ values.

The values of the phase shifts determine the relative amplitudes of different $(l, j)$ components.
CONCLUSION

The RMS value for different nuclei gradually increases with respect to the atomic mass no. both for the nuclei near the $\beta^+$ and $\beta^-$ stability line in the mass region 0 – 220 as shown in the figure 2 (A~0 – 40) and figure 3 (A~0 – 220). The N~Z graph for the different nuclei near and far from the $\beta$-stability line are shown in figure 1 (red line- $\beta^-$ stability nuclei, blue line- $\beta^+$ stability nuclei and black line- $\beta$ stability nuclei)

Figure 1: Neutron vs Proton no. for the nuclei in the mass region up to 220.

Figure 2: RMS radii vs atomic mass no. for nuclei near the $\beta^+$ stability line.
By designing a specific model to study the internal structure of these halo nuclei near and far from the stability line has wide applications in various fields.

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