Change of E_f and E_b for Superheavy elements from Z= 104-117

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Introduction

The d-block transactinide elements are generally known as the superheavy elements (SHE), which are extremely radioactive in nature. S. B. Duarte et al. have discussed α-decay systematics for superheavy elements by the method of α-clustering [1]. Yuejiao Ren and Zhongzhou Ren have calculated the half-lives and decay energies for double-β decay with two neutrinos they claim to be the future experimental search of double -β decay candidates [2]. However there is also possibility for the heavy nuclides to undergo spontaneous fission in competition with the α-emission. In this paper the binding energy and fission energy for SHE having atomic no. from 104-117 have been calculated and their behavior is shown graphically.

Methods

Spontaneous fission is predicted by the semi-empirical nuclear mass equation. Considering the case when the nucleus split into two roughly equal parts, the Q-value of the fission reaction

$$E_f = \left[{}^{A}_{Z}M - 2\left({}^{A/2}_{Z/2}M\right)\right]C^2 \qquad \text{-------- (1)}$$

Considering the Weizsaker's semi-empirical binding energy equation and neglecting the pairing term, equation (1) reduces to

$$E_f = \left[a_s\left\{A^{2/3} - 2\left(\frac{A}{2}\right)^{2/3}\right\} + a_c\left\{\frac{Z^2}{A^{\frac{1}{3}}} - 2\left(\frac{Z}{2}\right)^2 \Big/ \left(\frac{A}{2}\right)^{1/3}\right\}\right]C^2$$

Where, $a_s = 16.8\,Mev$

$a_c = 0.71\,Mev$

Thus for spontaneous fission,

$$\left[a_s\left\{A^{2/3} - 2\left(\frac{A}{2}\right)^{2/3}\right\} + a_c\left\{\frac{Z^2}{A^{\frac{1}{3}}} - 2\left(\frac{Z}{2}\right)^2 \Big/ \left(\frac{A}{2}\right)^{1/3}\right\}\right] \geq 0$$

From this relation the fission should be energetically possible for nuclei with A>100. However the fission does not take place even with many of the heavy nuclei. In order to explain this discrepancy A. Bohr and J.A. Wheeler considered the coulomb's potential barrier of the two fragments at the instant of separation. The existence of this barrier prevents the immediate breaking of these two. The barrier height corresponding to the coulomb potential between these two symmetric fragments when they are just in contact with each other is given by,

$$E_b = 0.15\left(\frac{Z^2}{A^{1/3}}\right)\ \text{MeV} \qquad \text{----------- (2)}$$

Thus the nucleus will be unstable and break apart into two fragments if $\boldsymbol{E_f > E_b}$

. Theoretical Framework

Fission is a process in which a heavy nucleus is caused to break into two roughly equal parts, known as fission fragments. Let us take an example of copernecium ($_{112}$Cn) to study the distribution of fission products. Taking the symmetric fission of ${}^{282}_{112}Cn$

$${}^{282}_{112}\mathrm{Cn}_{170} \rightarrow {}^{141}_{56}\mathrm{Ba}_{85} + {}^{141}_{56}\mathrm{Ba}_{85}$$

For the above reaction $E_f > E_b$, so ${}^{282}_{112}\mathrm{Cn}_{170}$ is energetically favorable to undergo fission process. In case of fission process very large disintegration energies are released and neutrons are emitted. For symmetric fission, the amount of energy released is more hence the fragments are in low energy state. So one should think of that there is more probability of symmetric fission but in practice, its probability is less. From the fission yield curve, the probability of asymmetric mass distribution is more than that of symmetric mass distribution. In the asymmetric splitting the amount of energy released is less hence, the fission fragments are in the higher energy state with high neutron to proton ratio becoming unstable, which undergo a chain of β-disintegration to a stable end product. Taking into account the neutron to proton ratio the probable asymmetric fission is

$$^{282}_{112}\mathrm{Cn}_{170} \rightarrow \, ^{120}_{48}\mathrm{Cd}_{72} + \, ^{160}_{64}\mathrm{Gd}_{96} + 2\mathrm{n}$$

Along with the two fission fragments, two neutrons are emitted known as prompt neutron which are evaporated from the neutron rich fragments. The number of neutrons in the fission fragments just after the fission is higher than what is required for the stable nucleus configuration. Hence the neutron rich fragments are β-active and undergo β^- decay to become stable.

$$^{120}_{48}Cd_{72} \xrightarrow{\beta^-} \, ^{120}_{49}\mathrm{In}_{71} \xrightarrow{\beta^-} \, ^{120}_{50}Sn_{70}$$

$$^{160}_{64}\mathrm{Gd}_{96} \xrightarrow{\beta^-} \, ^{160}_{65}\mathrm{Tb}_{95} \xrightarrow{\beta^-} \, ^{160}_{66}\mathrm{Dy}_{94}$$

Both the unstable neutron rich fragments comes to stable form after two β- decays.

Result and Discussion

To gain clear insight into the results, the variation in energies with the atomic mass no. A are shown in Fig. The graph shows that $\mathrm{E_f} < \mathrm{E_b}$ for 'A' less than 244, E_f becomes equal to E_b for atomic mass range A= 243-246, and $\mathrm{E_f} > \mathrm{E_b}$ for 'A' greater than 246. Thus the fission process becomes dominant for the superheavy region Z=104-117. It can

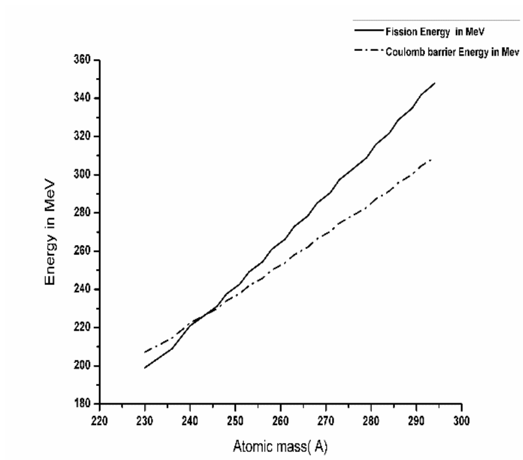

Fig.: variation of E_f and E_b with A

also be seen that the difference between the fission energy and barrier energy gradually increases with A for SHE. This change in the E_f and E_b shows that the splitting of a nucleus affects coulomb energy and surface energy. Since the division of the nucleus increases the separation between proton groups thus reducing their coulomb potential energy and the total nuclear surface which increases the surface energy. Moreover, since the nuclei near the middle of the periodic table have maximum binding energies $E_B \approx 8.5$ MeV/nucleon therefore the fission process is expected to release a large amount of energy.

References

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[3] Text book on Nuclear Physics by D.C.Tayal, 5th edition (HPH,Mumbai)