Spontaneous fission versus alpha radioactivity in heavy and super heavy nuclei

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Introduction

Theoretically, alpha decay and spontaneous fission share the same underlying mechanism in Physics, i.e. the quantum tunneling effect. The alpha decay process is considered as an alpha cluster penetrating the Coulomb barrier after its formation in the parent nucleus. As compared to alpha decay, the situation of spontaneous fission is much more complex and there are large uncertainties existing in the fission process such as mass and charge numbers of the two fragments, the number of emitted neutrons and released energy etc. In the case of super heavy elements spontaneous fission and alpha decay are the main decay modes. Super heavy nuclei which have relatively small alpha decay half life times compared to spontaneous fission half lives will survive fission and thus can be detected in the laboratory through alpha decay. The aim of this paper is to explore the possibility of finding long lived super heavy elements by comparing the calculated alpha decay half-lives with the spontaneous fission half-lives. We also propose a new semi-empirical formula for determining spontaneous fission half lives.

Spontaneous fission half lives

The first semi-empirical formula for spontaneous fission half-lives of even-even, odd A and odd-odd nuclei in the ground state was proposed by Swiatecki in 1955 and successfully reproduced the experimental data with this formula. Using the macroscopic-microscopic approach, Smolanczuk et al studied the quantities like potential energy, the effective inertia along the fission trajectory and computed the spontaneous fission half lives of even-even nuclei with proton number Z = 104-114 and neutron number N=142-176. Ren et al [1] proposed a formula for calculating the half life of spontaneous fission given as

$$\log_{10}(T_{1/2}/yr) = C_1\frac{(Z-90-\nu)}{A} + C_2\frac{(Z-90-\nu)^2}{A} + C_3\frac{(Z-90-\nu)^3}{A} + C_4\frac{(Z-90-\nu)(N-Z-52)^2}{A} + d \quad (1)$$

where C_1 = -548.825021, C_2 = -5.359139, C_3 = 0.767379, C_4 = -4.282220 and d = 21.08, the seniority term ν was introduced taking the blocking effect of unpaired nucleon on the transfer of many nucleon-pairs during the fission process and ν =0 for spontaneous fission of even-even nuclei, ν =2 for odd A and odd-odd nuclei.

Semi-empirical formula

A new semi empirical formula is proposed for determining the spontaneous fission half lives and is given as

$$\log_{10}(T_{1/2}/yr) = a\frac{Z^2}{A} + b\left(\frac{Z^2}{A}\right)^2 + c\frac{(N-Z)}{(N+Z)} + d\left[\frac{(N-Z)}{(N+Z)}\right]^2 + e \quad (2)$$

The constants are, a = -43.25203, b = 0.49192, c = 3674.3927, d = -9360.6 and e = 580.75058.

Results and discussion

We have computed the alpha decay half life times of isotopes with Z = 100-122 using Coulomb and Proximity Potential Model [2] and the spontaneous fission half-lives of even-even isotopes with Z=100-138 is computed using the phenomenological formula (eqn. 1). The computed alpha decay and spontaneous fission half lives for all the isotopes are in close agreement with the experimental data.

We have studied the Seaborg plots connecting the spontaneous fission half lives versus fissionability parameter (Z^2/A) for isotopes with Z = 100-138. But from the plots we can see that spontaneous fission half lives increases with the proton number Z, which is a slight increase for Z=100 to Z=118 and a sharp increase for Z=120 to Z=138. This trend is different from the earlier observation of Studier et al [3]. For a fixed neutron number, the neutron separation energy increases with increasing proton number. Increase in proton number Z, increases the fissility parameter which pulls in maximum of liquid drop energy to make the peak of first hump higher than second. So when protons are added beyond shell closure Z=120 the barrier height increases gradually which result in reduced fission probability (increased half life) from Z=120 to 138.

We have studied the plots connecting spontaneous fission half lives against relative neutron excess, I = (N-Z)/(N+Z) for Z = 100-138. It is evident from these plots that the curves converge at a single point (at 0.2) and afterwards it diverges. This point corresponds to the value Z/A = 0.4 which is the mechanism of nuclear fission established by the limit for spontaneous fission. i.e. the isotopes with neutron excess less than or equal to 0.2 are the probable candidates which can survive spontaneous fission. Figure 1 represents the plot for ratio of spontaneous fission with alpha decay half lives against relative neutron excess for nuclei with Z = 100-122. It is also obvious from this plot that the curves converge to a single point (at 0.2) and then diverge. It is clear that the isotopes in the first quadrant of this plot have alpha decay as the dominant mode of decay. So these isotopes ($^{246-256}$Fm, $^{252-260}$No, $^{256-262}$Rf, $^{260-266}$Sg, $^{264-270}$108, $^{268-276}$110, $^{272-280}$112, $^{274-284}$114, $^{278-290}$116, $^{280-294}$118, $^{284-300}$120 and $^{288-304}$122) will survive fission and can be synthesized and identified via alpha decay. We presume that the present work on spontaneous fission versus alpha decay of super heavy elements will be a guide to future experiments.

The present semi empirical formula (eqn. 2) for spontaneous fission works well for the mass region from ^{232}Th to ^{286}114 and with other semi empirical formula predictions. Figure 2 represents the comparison of the present spontaneous fission half lives for ^{232}Th to ^{250}Cm with the formulas of Ren et al [1] and Xu et al[4] and with the experimental values. It is obvious from the plot that our computed half lives are in close agreement with the experimental data and with other emperical formula predictions. From experimental spontaneous fission half life time values of 45 nuclei, the estimated standard deviation is found to be 1.427353. We have also computed the standard deviations for the emperical formulas of Ren et al [1], Xu et al [4] and are found to be 2.853711 and 1.27461 respectively. It is clear that the present formula is better than the formula of Ren et al [1]. The formula of Xu et al [4] is better than the present formula but it employs seven parameters and five variables A, Z^2, Z^4, $(N-Z)^2$ and $Z^2/A^{1/3}$ while the present formula employs only five parameters and four variables.

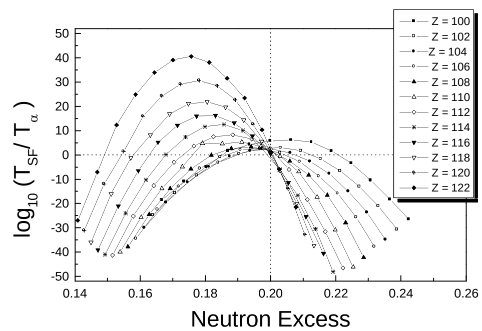

Fig. 1 The ratio of spontaneous fission and alpha decay half lives against relative neutron excess of even-even parents with Z = 100-122.

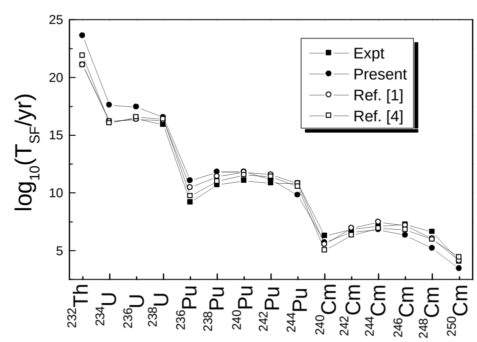

Fig. 2 The comparison of present, other semi empirical formula predictions with experimental spontaneous fission half life time values for various parents.

References

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