Nuclear mass transfer in the decay of Plutonium isotopes

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Introduction

Spontaneous fission is one of the general feature of radioactive nuclei. The spontaneous decay of parent nuclei to various decay channels namely $\alpha-$decay, cluster radioactivity, and spontaneous fission may take place at various choices of neck length parameter such as zero (touching configuration), positive (above touching) and negative (overlapping configuration) [1]. For these configurations, two different versions of the classical model were proposed by Kröger and Scheid [2] to explain the mass transfer which are briefly discussed in the subsequent section. In the present work, an attempt is made to analyze the relative effect of using two different versions of the classical model on the mass transfer, structural profile and half-life time for the spontaneous fission of Pu isotopes, particularly in the overlap region.

Preformed Cluster Model (PCM)

The preformed cluster model (PCM) [3] uses the dynamical collective coordinates of mass and charge asymmetries (η and η_Z) and the relative separation R on the basis of Quantum Mechanical Fragmentation Theory. The half-life $T_{1/2}$, or the decay constant λ in PCM is defined as,

$$\lambda = \nu_0 P_0 P, \quad T_{1/2} = \frac{ln\ 2}{\lambda} \tag{1}$$

Here ν_0 is the barrier assault frequency, P_0 is the cluster preformation probability, P is the barrier penetrability which refer, respectively, to the η and R motions. P_0 are the solutions of the stationary Schrodinger equation in η,

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

which on proper normalization is given by

$$P_0 = |\psi(\eta(A_i))|^2 \sqrt{B_{\eta\eta}}\frac{2}{A}. \tag{3}$$

and this provides necessary structure information in the decay process of a nuclear system. $B_{\eta\eta}$ are the classical hydrodynamical masses of Kröger and Scheid [2] which are given by two different versions of the classical model.
(a) In the first approach (Model A), the hydrodynamical mass is given by

$$B_{\eta\eta} = \frac{MR^2}{4}\left(\frac{V}{V_0} - 1\right) \tag{4}$$

Here M is the total mass, V is the total conserved volume and $V_0=\pi RR_n^2$ is the cylindrical inner region bounded by the centres of the semi-spheres and the neck with radius R_n (see figure 1(a) of Ref [2]).
(b) In the second version of the model (Model B), radial flow is assumed between the spherical surfaces with $R_{i=1,2}$ and R_t and an homogeneous flow in the cylinder with radius R_t and length R between the two nuclear volumes (see figure 1(b) of Ref [2]). The transfer mass is given as:

$$B_{\eta\eta} = \frac{MR^2}{4}\left(\frac{V(1+\beta)}{V_c(1+\gamma)^2} - 1\right) \tag{5}$$

$$\beta = \frac{R_t}{2R}\left[\frac{1}{1+cos\ \theta_1}\left(1-\frac{R_t}{R_1}\right) + \frac{1}{1+cos\ \theta_2}\left(1-\frac{R_t}{R_2}\right)\right]$$

$$\gamma = \frac{1}{2R}[(1-cos\ \theta_1)(R_1-R_t)+(1-cos\ \theta_2)(R_2-R_t)] \tag{6}$$

and $V_c=\pi R_t^2 R$, where

$$R_t = 0.4\ min(R_1, R_2) f(R/R_{crit}) \tag{7}$$

f(x)=1 if x≤1; f(x)=$\sin^2 \frac{1}{2}\pi$x if 1≤x≤2.
The model allows mass transfer for separated nuclei if $R_t \neq 0$ for $R>R_1+R_2$. It is relevant to mention that this approach is extensively excercised on various DCM based calculations.

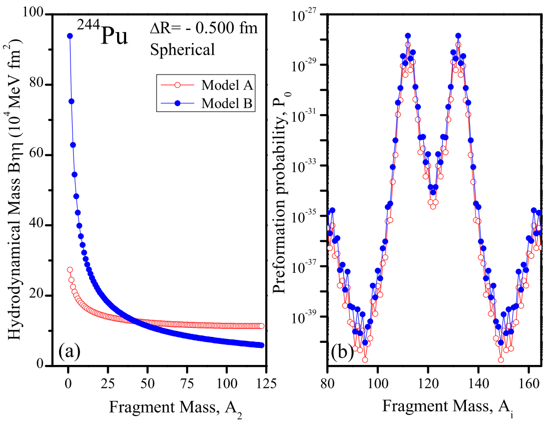

FIG. 1: Effect of using two different versions of the classical model on the (a) Hydrodynamical mass parameter ($B\eta\eta$) and (b) Preformation probability in the ground state decay of ^{244}Pu.

TABLE I: The PCM calculated preformation probability P_0, and half-life time $T_{1/2}$(sec) for the spontaneous fission of Pu isotopes with two different versions of the classical model viz. Model A and Model B.

$\log_{10}$ **P$_0$**		$\log_{10}$**T$_{1/2}$(sec)**		
Model A	Model B	Model A	Model B	Expt.
^{238}Pu $\longrightarrow$ ^{104}Mo+^{134}Te; ΔR=-0.330 fm				
-28.56	-27.91	18.89	18.24	18.17
^{240}Pu $\longrightarrow$ ^{106}Mo+^{134}Te; ΔR=-0.380 fm				
-28.15	-27.67	18.60	18.13	18.56
^{242}Pu $\longrightarrow$ ^{106}Mo+^{136}Te; ΔR=-0.360 fm				
-30.45	-29.68	19.08	18.31	18.32
^{244}Pu $\longrightarrow$ ^{112}Ru+^{132}Sn; ΔR=-0.500 fm				
-28.20	-27.85	18.71	18.32	18.31

Results and Discussions

In Fig. 1, the hydrodynamical mass parameter and preformation probability is plotted as a function of fragment mass for the decay of ^{244}Pu using the two different versions of the classical model viz. Model A and Model B. It is clear from the figure that using two different versions of the classical model, transfer of mass is significantly influenced. The mass transfer is higher for the light particles and the cluster region for Model B, whereas in the heavy particle and fission region, the situation gets reversed. This is due to the different values of the radius and volume of the cylinder in these two approaches through which the mass transfer takes place. The radius of cylinder in case of Model A is a function of overlapping distance whereas for Model B, it depends upon the radii of colliding nuclei. The transition mass number varies with the mass of decaying nuclei because of different overlapping distance. Also, with increase in the mass asymmetry of the decaying fragments, larger mass transfer takes place using the two models. The preformation structure of the ^{244}Pu is similar for both choices of mass transfer, with evident difference in magnitude, and this result is consistent for ^{238}Pu, ^{240}Pu, and ^{242}Pu also. The change of magnitude in preformation probability affects the half-life time of the decaying nuclei as discussed below.

In Table I, the calculated preformation probability and the decay half-lives for the spontaneous fission using Model A and Model B for Plutonium isotopes particularly ^{238}Pu, ^{240}Pu, ^{242}Pu and ^{244}Pu are tabulated. From the table, it is observed that the preformation probability and the decay half-life are different in the spontaneous fission of four Plutonium isotopes within two choices of the mass transfer. The half-life time calculated with Model A are higher than that with Model B.

Acknowledgments

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References

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