Semiclassical calculation of activation energies of fission in superheavy nuclei

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Introduction

The basic study of fission process usually involves the calculation of fission barrier heights, relative fission fragment mass and charge distributions and their kinetic energies etc [1,2,3]. The estimation of fission barriers are of vital importance in determining the probability of fission process in comparison to other competing processes such as α, β and other decay modes.

With the experimental advancement in the field of production of Superheavy nuclei(SHN), there has been tremendous efforts in their stability analysis and the ultimate goal is to reach the hypothetical island of stability [4]. Spontaneous fission is an important decay mode in such nuclei besides the α decay process. This work aims towards the calculation of activation energies of fission(the potential barrier that has to be climbed) in superheavy nuclei within the microscopic-macroscopic approach [5] by utilizing the semiclassical trace formula for spherically symmetric harmonic oscillator potential with spin-orbit interactions [6] for the calculation of shell corrections.

Semiclassical calculation of fission activation energies E_f

The activation energy required for fission is determined as the difference between the total interaction potential of the parent nucleus and the disintegration energy of fission process i.e.$(V - Q)$. Here the proximity potential V is defined as, for $z > 0$ [2]:

$$V = \frac{Z_1 Z_2 e^2}{r} + V_P(z) \tag{1}$$

where, Z_1, Z_2 refers to the charge number of the two emitted fission fragments. r is the distance between centers of fragments and z is the separation between their two near surfaces, $r - C_1 - C_2$, where, $C_1$and C_2 are the Süsmann central radii of fragments. The proximity potential $V_P(z)$ used in the calculations is taken as in [2]. For $z < 0$, i.e. for the internal part (overlap region) of the barrier, the barrier is given as,

$$V = a_0(L - L_0)^n \tag{2}$$

where, the constants a_0, n are chosen, such that the smooth matching of the two potentials (for $z < 0, z > 0$) is ensured.
Next, the calculation of decay energy $Q-$value is carried out using the recently proposed microscopic-macroscopic approach [5], with the inclusion of shell corrections through the semiclassical techniques [6,7] as:

$$Q = B_1(Z_1, A_1) + B_2(Z_2, A_2) - B(Z, A) \tag{3}$$

where, the calculations of binding energies of parent $B(Z, A)$, daughter fragments $B_1(Z_1, A_1), B_2(Z_2, A_2)$ is carried out as described in [5]:

$$B'(Z,A) = a_v(1 - k_v I^2)A - a_s\left(1 - k_s I^2\right)\left(1 + \frac{2}{5}\beta_2^2\right)A^{\frac{2}{3}} - a_c\frac{e^2 Z^2}{r_0 A^{\frac{1}{3}}}\left(1 - \frac{1}{5}\beta_2^2\right) + a_d\frac{Z^2}{A}$$

$$
\begin{aligned}
& - \quad a_w |N - Z| \exp^{-(A/50)^2} \\
& + \quad a_{w'} \exp^{-80I^2}, \qquad (4) \\
B(Z, A) \quad & = \quad B^{'}(Z, A) + \delta U. \qquad (5)
\end{aligned}
$$

where $I = \frac{N-Z}{A}$ is the isospin factor, β_2 is the quadrupole deformation parameter [8], $r_0 = 1.2271$ fm and $e^2 = 1.44$ MeV fm. The first three terms include volume, asymmetry, surface and coloumb energy with $a_v = 15.3982$ MeV, $k_v = 1.7546$, $a_s = 17.3401$ MeV, $k_s = 1.5981$ and $a_c = 0.6$. While the fourth term represents the diffuseness correction to the sharp radius coulomb energy having $a_d = 1.0867$ MeV. Wigner's supermultiplet theory based on SU(4) spin-isospin symmetry was utilized to introduce fifth term with, $a_w = 0.356$ MeV while the sixth term describes the neutron-proton pairing at zero temperature where $a_{w'} = 1.359$ MeV. δU refers to the microscopic shell corrections. Instead of using BCS formalism, the pairing energy term is simply approximated by the liquid drop term $\pm 33.6\ A^{-3/4}$(for even-even and odd-odd nuclei respectively). Having determined both the interaction potential and the $Q-$value, we can now determine the difference of the two, referred to as the potential barrier height E_f.

Results and Discussion

The potential(V) as a function of distance between the centers of fission fragments(r) obtained for several $Z = 114$(Flerovium isotopes) are plotted in Fig. 1. The obtained fission barriers are listed in table 1. Here we have considered only the symmetric fission of $Z = 114-$ isotopes.

Parent Nucleus	$Q(MeV)$	Barrier height(MeV)
$^{270}114$	338.935	5.792
$^{272}114$	335.188	8.464
$^{274}114$	336.425	6.169

Table 1: Q-values and fission barrier heights E_f in case of symmetric fission for $Z = 114$ isotopes.

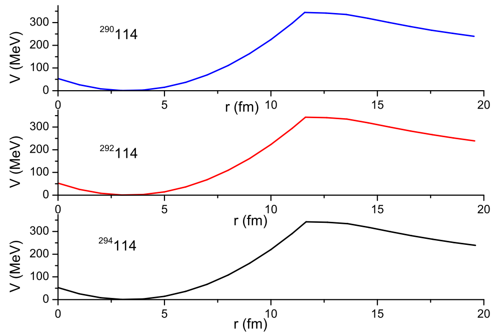

Figure 1: Total interaction potential $V(r)$ as a function of distance r between the binary fragments for $^{270,272,274}114$.

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