Lifetime estimation of fusion-fission and quasi fission processes for Nobelium isotopes

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Introduction

The quest for the heaviest element in the nuclear landscape has yielded many surprises and enhanced the understanding of nuclear reactions which further attributed to play a crucial role in the expansion of the Periodic Table through synthesis of new elements and corresponding of isotopes. Persistent theoretical and experimental efforts has been made to investigate various reaction conditions and their subsequent decay mechanisms. The study of dynamics of massive nuclei collisions near the Coulomb barrier energies manifests that the complete fusion of reactants do not take place immediately upon contact of nuclei whereas the complete fusion process is strongly hindered by fission, quasi fission and fast fission processes. If the composite system is fully equilibrated, it involves complete amalgamation of projectile and target which forms a compound nucleus (CN) stage, which may decay into the evaporation residue (ER) and fusion-fission (ff) fragments. In a non-equilibrated fused system i.e. non-compound nucleus (nCN) reseparates by transferring only few nucleons, thus giving rise to different decay processes such as quasi fission (QF), fast fission (FF) etc. The measurement of lifetime can give definitive signature of the nuclear reaction process. The parameters of the fissioning nucleus such as the fissility, deformation and excitation energy etc play an important role to determine the lifetime of the decay process. Processes such as quasi fission (QF) generally take place on short time around 10^{-21} s to 10^{-20} s while fusion-fission (ff) occurs on longer time scales [1]. The synthesis of the heavy and superheavy elements are strongly hindered by the nCN processes which leads to faster splitting of fragments and the efforts are being done to study the timescales of such processes [2, 3]. In this work, we aim to estimate the time scales of quasi fission (QF) and fusion-fission (ff) using Dynamical cluster decay model (DCM) and compare the results with dinuclear system (DNS).

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Methodology

The lifetimes for fusion-fission (ff) and quasi fission (QF) are examined using the theoretical approach and is given by

$$\tau_{ff|QF} = \frac{1}{\lambda_{ff|QF}} \qquad (1)$$

where $\lambda_{ff|QF}$ is the fusion-fission or quasi fission decay constant. More can be found in references [2, 3].
The comparison is done with lifetimes calculated using the Dynamical cluster decay model (DCM) [5] by employing the Skyrme energy density formalism (SEDF) [4].

Results and Discussions

Fig.1 shows the variation of scattering potential at $\ell = 0\hbar$ for ^{40}Ca + $^{208}Pb \rightarrow {}^{248}No^*$ $\rightarrow A_1 + A_2$ reaction at centre mass energy $E_{c.m.}$ = 187.03 MeV as a function of range R (fm). It may be noted that the first turning point R_a ($= R_1 + R_2 + \Delta R$), represent the internuclear separation at which the fragments are considered to be preformed and start penetrating through the interaction barrier. Similarly, R_b, second turning point, where penetration through interaction barrier gets completed. The quasi fission barriers is marked and is defined as the difference between the potentials at the barrier V_B and the potential corresponding to the first turning point $V(R_a)$

Reaction	$E_{c.m.}$ (MeV)	E^*_{CN} (MeV)	T (MeV)	τ^{DCM}_{ff} (sec^{-1})	τ^{DNS}_{ff} (sec^{-1})	τ^{DCM}_{QF} (sec^{-1})	τ^{DNS}_{QF} (sec^{-1})
$^{40}Ca +^{208} Pb$	187.03	49.0	1.35	1.39 $\times 10^{-16}$	4.98$\times 10^{-19}$	3.42 $\times 10^{-21}$	5.41 $\times 10^{-21}$
	209.67	94.0	1.64	5.45$\times 10^{-16}$	2.39$\times 10^{-19}$	3.68 $\times 10^{-21}$	3.12$\times 10^{-21}$
	238.19	101.0	1.93	1.78$\times 10^{-16}$	1.45$\times 10^{-19}$	3.93$\times 10^{-21}$	2.14$\times 10^{-21}$
$^{44}Ca +^{206} Pb$	187.04	38.7	1.16	4.80$\times 10^{-18}$	1.50$\times 10^{-18}$	3.01$\times 10^{-21}$	1.46$\times 10^{-20}$
$^{64}Ni +^{186} W$	231.38	40.0	1.21	3.46$\times 10^{-17}$	1.18$\times 10^{-18}$	1.18$\times 10^{-21}$	1.41$\times 10^{-21}$

TABLE I: Fusion-fission lifetime τ_{ff} and Quasi fission lifetime τ_{QF} for different reactions used for the formation of $^{248}No^*$ and $^{250}No^*$ at different excitation energies within the DCM and compared with DNS approach.

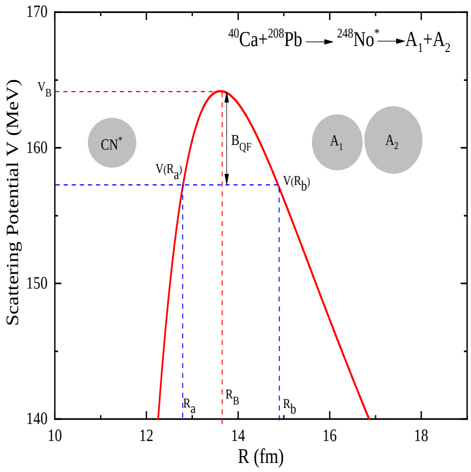

FIG. 1: Scattering potential V (MeV) as a function of range R (fm) for the entrance channel of $^{248}No^*$ nuclei at $\ell = 0\hbar$ at the centre of mass energy $E_{c.m} = 187.03$ MeV.

as a function of angular momentum for the incoming channel at the above mentioned incident energy.

The time scale of fusion-fission and quasi fission processes are extremely important from the experimental and theoretical point of view as the knowledge of the lifetime is crucial for the understanding of the nuclear reaction process. The total time involved in a fission process can be schematically divided in two main components i.e. the time needed for the nucleus to pass over the saddle point and the deformation time from the saddle point up to the scission point. While for the quasi fission, its barrier depends upon Z_1Z_2 product, which in turn influence its lifetime. Hence, the time may not be sufficient to transform into a compound nucleus and the quasi fission process takes place. The fission and quasi fission lifetime are calculated for $^{248}No^*$ (^{40}Ca + ^{208}Pb) and for $^{250}No^*$ ($^{44}Ca +^{206} Pb$ and $^{64}Ni +^{186} W$) reactions [6, 7]. Table I, shows the comparison of fusion-fission τ_{ff} and quasi fission lifetime τ_{QF} using the excitation energy E^*_{CN} within the DCM and DNS approaches [2, 3]. It is observed that the ff and qf lifetime τ_{ff} / τ_{QF} decreases with increase in the excitation energy E^*_{CN}. Therefore, the stability of the massive compound nucleus decreases due to the reduction of the fission barrier by increasing its excitation energy. On comparing the lifetimes obtained using the DCM and DNS approaches, difference is observed for the ff channel, whereas the qf lifetimes are almost similar for both the approaches.

References

[1] D. J. Hinde *et al.*, Phys. Rev. Lett. **74**, 1295 (1995).

[2] S. Soheyli *et al.*, Phys. Rev. C **94**, 034615 (2016).

[3] M. V. Khanlari *et al.*, Phys. Rev. C **95**, 024617 (2017).

[4] B.K. Agrawal *et al.*, Phys. Rev. C **73**, 034319 (2006).

[5] R. K. Gupta, in Clusters in Nuclei, Lecture Notes in Physics 818, Vol. I, p. 223.

[6] E. M. Kozulin *et al.*, Phys. Rev. C **105**, 024617 (2022)

[7] G. N. Knyazheva *et al.*, Phys. of Part. and Nucl. Lett. Vol. **5** No. 1 (2008).