# Impact of odd-odd and even-even target-projectile on particle multiplicities

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## Introduction

One of the most interesting areas of nuclear physics is nuclear fission, which entails enormous nucleus rearrangement. Even though a great deal of studies has been done over many years, much more is yet to be established. A projectile and a target must interact during the numerous phases of the fission process in order to generate an intermediate compound nucleus that finally breaks into fragments. Because of its extreme instability, the intermediate state which exists for a brief period of time emits protons, neutrons, alpha, and gamma rays. Particles released from the compound nucleus during the fission process are referred to as pre-scission particles, and particles released from the fragments in the course of the procedure are referred to as post-scission particles.

The fission products provide insights into the dynamic evolution, which makes them highly interesting. Neutron measurements have provided the majority of the information regarding the fusion-fission dynamics of heated rotating nuclei generated in heavy-ion-induced events. These measurements show that the fission process is dissipative in nature at high excitation energies. Charged particles are also employed in certain measurements as a probe to examine the kinematics of fusion and fission [1-4]. So, studying particle multiplicities will help us to know about the dynamics and the time scales making them extremely beneficial.

## Theoretical Framework

To comprehend the dissipation strength in the fusion-fission process, statistical model computations were performed utilizing the JOANNE2 code. It replicates the simultaneously measured neutron and α particle pre-scission multiplicities by using the deformation-dependent particle binding energies and transmission coefficients. The pre-scission particle emission in this model is thought to originate from two locations in the deformation space. Z is the elongation of the symmetry axis (in units of the spherical nucleus diameter), and the first corresponds to mean pre-saddle deformation ($Z_{tr}$) and the second to mean saddle-to-scission deformation ($Z_{ssc}$). The two main components of fission time are the transient time ($\tau_{tr}$), which is the amount of time required to go from the equilibrium compound state to the saddle point, and the descent time from the saddle to the scission point, which is termed as saddle to scission time ($\tau_{ssc}$). The strength of the nuclear medium's viscosity can be determined from the fission times. Stronger nuclear viscosity is indicated by larger values of the fission times scales. Variations in pre-saddle time ($\tau_{tr}$), saddle-to-scission time ($\tau_{ssc}$), and deformation ($Z_{ssc}$) have been statistically calculated and their impact on $\nu_{pre}$ and $\alpha_{pre}$ are observed [5-8].

## Results and Discussions

Here, we have done theoretical calculations for two reactions forming the same compound nucleus $^{198}Tl^*$. Table 1 below shows the theoretically calculated multiplicities for neutron

**Table 1:** Theoretically calculated neutron and alpha particle multiplicities for $^{10}B+^{188}Os \rightarrow ^{198}Tl^*$.

| $E_{lab}$ (MeV) | Fusion Cross section(mb) | Fission Cross section(mb) | $\nu_{pre}$ | $\alpha_{pre}$ |
|---|---|---|---|---|
| 160 | 1823.5 | 182.3 | 7.94 | 0.167 |
| 165 | 1834.6 | 209.1 | 8.26 | 0.204 |
| 170 | 1845.1 | 226.9 | 8.62 | 0.220 |

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and alpha for $^{10}B+^{188}Os$ nuclear reaction. Table 2 represents neutron and alpha multiplicities for the $^{19}F+^{179}Hf$ nuclear reaction. Both reactions have been computed for the same set of energies having an interval of 5 MeV.

**Table 2:** Theoretically calculated neutron and alpha particle multiplicities for $^{19}F+^{179}Hf \rightarrow ^{198}Tl^{*}$.

| $E_{lab}$ (MeV) | Fusion Cross section (mb) | Fission Cross section (mb) | $\nu_{pre}$ | $\alpha_{pre}$ |
|---|---|---|---|---|
| 160 | 1545.8 | 123.6 | 5.89 | 0.093 |
| 165 | 1574.4 | 141.7 | 6.26 | 0.109 |
| 170 | 1601.3 | 177.7 | 6.61 | 0.126 |

It is clear from both tables that the even-even combination of target-projectile has a larger value than the odd-odd combinations when it comes to neutron multiplicities. Alpha multiplicities follow the same pattern.

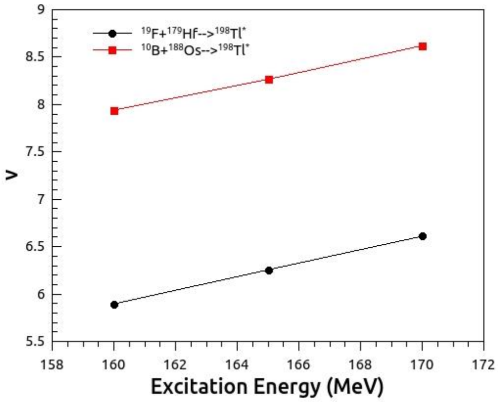

**Fig. 1**: Theoretically calculated neutron multiplicities for $^{198}Tl^{*}$ compound nucleus.

Fig. 1 shows the computed neutron multiplicity for target projectile combinations that are odd-odd versus even-even, with the even-even target projectile combination having a larger value for neutron multiplicity. Fig. 2 illustrates how alpha multiplicity follows neutron multiplicity.

## Summary

We can conclude that nuclear fusion-fission dynamics can be determined by particle multiplicities (neutron, alpha). Also, mass asymmetry (α) has a critical role in multiplicity measurements. Finally, it can be concluded that nuclear dissipation reduces with increasing degree of entrance channel mass asymmetry in the fusion-fission process.

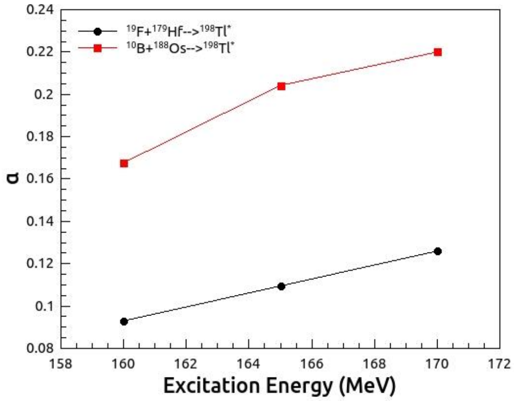

**Fig. 2**: Theoretically calculated alpha multiplicities for $^{198}Tl^{*}$ compound nucleus.

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## References

[1] K. Kapoor et al., Phys. Rev. C **100**, 014620 (2019).

[2] A. Chatterjee et al., Phys. Rev. C **52**, 6 (1995).

[3] A. Saxena et al., Phys. Rev. C **49**, 2 (1994).

[4] K. Ramachandran et al., Phys. Rev. C **73**, 064609 (2006).

[5] H. Ikezoe et al., Phys. Rev. C **49**, 9 (1994).

[6] J. P. Lestone, Phys. Rev. C **70**, 15 (1992).

[7] D. J. Hinde et al., Nuclear Physics A **502** (1989).

[8] D. J. Hinde, Phys. Rev. C **45**, 3 (1992).