Compound nucleus formation probability for Ca-induced fusion reactions

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Introduction

Compound nucleus formation probability (P_{CN}) is the important quantity in finding angular distributions in heavy ion reactions. Initially, the formation of a compound nucleus was thought to occur when a bombardment particle transferred its energy to the target nucleus, resulting in a very unstable compound nucleus. This unstable nucleus eventually evaporates one or more light charged particles and becomes a stable nucleus. The capture process, the probability of compound nucleus formation, and the de-excitation during stable nucleus formation all have a significant impact on the production of evaporation residues.

The cross sections of capture and fission, P_{CN} and survival probability (P_{surv}) of superheavy nuclei Z=126 were predicted by using different projectiles. The synthesis of superheavy element Z=122 were predicted using different projectile-target combinations such as Cr+Cf, Fe+Cm, Se+Ra and As+Ac [1]. Earlier researchers [2] investigated P_{CN} and P_{surv} of superheavy element Z=117. Formation of compound nuclei and evaporation residue cross sections were predicted in superheavy region [3]. Iron and Nickel projectiles were used in the evaluation of evaporation residue cross sections for Z>118 [4-8]. Sowmya et al., [9] investigated accurate neutron and fission decay width for the hot fusion reactions. Yanez et al., [10] predicted P_{CN} for the hot fusion reactions. Using dynamical cluster model [11], P_{CN} is investigated for the hot fusion reactions.

Hence, in the present work we investigated experimentally available ^{48}Ca induced fusion reactions and studied fusion cross sections, capture cross sections and formation of compound nuclei.

Theoretical Framework:

The fusion cross sections of ^{48}Ca induced reactions are taken from the experimental data available in literature [12].

The capture cross section is the sum of fusion, quasifission and fastfission cross sections.

$$\sigma_{cap} = \sigma_{fusion} + \sigma_{quasifission} + \sigma_{fastfission} \qquad (1)$$

While the fusion cross section is given by;

$$\sigma_{fusion} = \sigma_{fusion-evaporation} + \sigma_{fusion-fission} \qquad (2)$$

Further, P_{CN}[10] is the ratio of fusion cross section to the capture cross sections and it is defined as follows;

$$P_{CN} = \frac{\sigma_{fusion}}{\sigma_{capture}} = \frac{\sigma_{fusion} - \sigma_{quasifission} - \sigma_{fastfission}}{\sigma_{capture}} \qquad (3)$$

Results and Discussions:

Fusion cross sections of ^{48}Ca induced fusion reactions such as ^{48}Ca+^{154}Sm, ^{48}Ca+^{168}Er, ^{48}Ca+^{170}Er and ^{48}Ca+^{208}Pb were investigated using the data available in literature [12]. The capture cross sections are evaluated using HIVAP code [13,14]. The formation of compound nuclei is evaluated using the equation given in theory section. For an instance, we have plotted variation of fusion cross section as a function of center of mass energy as shown in figure 1(a). The fusion cross section gradually increases and attains a maximum value. Similar trend is also observed for the capture cross section as seen in figure 1(b). The formation of compound nuclei is evaluated and it is plotted as a function of $\frac{E_{cm}}{E_{Bass}}$. In this particular case, P_{CN} reaches a maximum value up to 10^{-1} order.

Similarly we have evaluated P_{CN} for other possible fusion reactions such as ^{48}Ca+^{154}Sm, ^{48}Ca+^{168}Er and ^{48}Ca+^{170}Er. Further, we have fitted suitable empirical formulae for P_{CN} as a function of $\frac{E_{cm}}{E_{Bass}}$. The empirical formulae are fitted as given below;

$$P_{CN}(E_{cm}) = \frac{P_0}{1+\exp\left[\alpha\left(\beta - \frac{E_{cm}}{E_{Bass}}\right)\right]} \quad (4)$$

here, P_0, α and β are the fitting constants. These fitting constants are tabulated in table 1 for the ^{48}Ca induced fusion reactions.

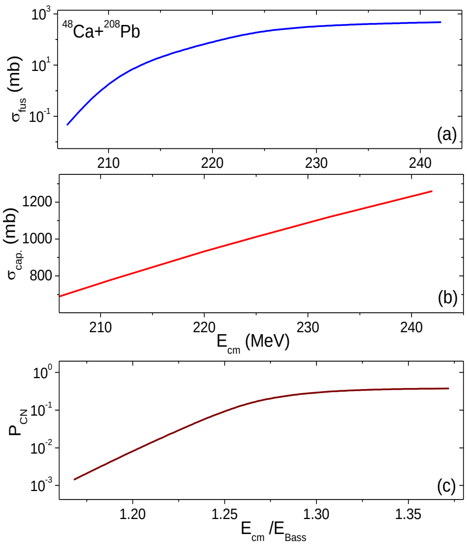

Fig. 1: (a) A plot of fusion cross section as a function of center of mass energy, (b) a plot of capture cross section as function of center of mass energy and (c) compound nucleus formation probability as function of $\frac{E_{cm}}{E_{Bass}}$ for the fusion reaction of ^{48}Ca+^{208}Pb.

Table 1: Tabulation of fusion reactions, E_{Bass} and fitting constants such as P_0, α and β.

Reaction	E_{Bass}	P_0	α	β
^{48}Ca+^{154}Sm	139.11	1.389	16.452	1.099
^{48}Ca+^{168}Er	150.89	0.1425	33.648	2.051
^{48}Ca+^{170}Er	150.52	0.1571	31.862	2.066
^{48}Ca+^{208}Pb	176.37	0.3783	56.203	1.267

Conclusions:

We have investigated ^{48}Ca induced fusion cross sections such as ^{48}Ca+^{154}Sm, ^{48}Ca+^{168}Er, ^{48}Ca+^{170}Er and ^{48}Ca+^{208}Pb. We have evaluated capture cross sections using HIVAP code. The semi-empirical relation is proposed for the compound nucleus formation probability as a function of $\frac{E_{cm}}{E_{Bass}}$. The proposed semi-empirical relation can be used in the prediction of compound nucleus formation probability for the ^{48}Ca induced fusion reactions.

References

[1] H. C. Manjunatha et al., Phys Rev C, **98**, 024308 (2018).

[2] H.C. Manjunatha et al., Eur. Phys. J. A **53**, 97 (2017).

[3]] P.S.Damodara Gupta, et al., Pramana **96**, 146 (2022).

[4] H.C.Manjunatha et al., Nucl.Phys. A **987,** 382 (2019).

[5] H.C.Manjunatha et al., Can. J. Phys. **99**, 16 (2021).

[6] H.C. Manjunatha et al., Phys Rev C **102**, 064605 (2020).

[7] H.C. Manjunatha et al., Phys. Rev. C **103**, 024311 (2021).

[8] H. C. Manjunatha et al., Phys. Rev. C **104**, 024622 (2021).

[9] N. Sowmya, et al., Phys. Rev. C **105**, 044605 (2022).

[10] R. Yanez, Phys. Rev. C **88**, 014606 (2013).

[11] Arshdeep Kaur et al.,Phys. Rev. C **90**, 024619 (2014)

[12] http://nrv.jinr.ru/nrv/webnrv/fusion/ .

[13] W. Reisdorf, Z. Phys. A **300**, 227 (1981).

[14] W. Reisdorf and M Sch¨adel, Z. Phys. A **343**, 47 (1992).