Analysis of ^{9}Be + ^{197}Au fusion cross section at above barrier energies

Rajiv Chahal[a*] and Manjeet Singh Gautam[b#]
[a*] Department of Physics, K. M. Govt. College Narwana, Jind-126116, Haryana, India,
[b]Department of Physics, Govt. College Alewa, Jind-126102, Haryana, India,
*rajivchahal@mail.com, #gautamanjeet@gmail.com

The fusion of weakly bound nucleus with medium mass and heavy target is hot topic from last two decades. Due to low breakup threshold, the weakly bound nucleus can splits into two or more components and results in the partial absorption of the projectile by the target nucleus. This in turn leads to the reduction of incoming flux going into fusion channel. Such loss of flux from fusion channel is responsible for the suppression of complete fusion (CF) cross section at above barrier energies [1]. This behavior of fusion of weakly bound nuclei with heavy target seems to be general feature of heavy ion reaction involving loosely bound systems.

In this regards, in the present paper the fusion dynamics of ^{9}Be+^{197}Au reaction is theoretically investigated by using the Classical Dynamical Model. The Classical Dynamical Model was introduced by A. Diaz-Torres [1-3] and calculations are done by using the code PLATYPUS [4]. For the chosen reaction, the model calculations predict that 34-37% of total fusion (TF) cross sections appeared as incomplete fusion (ICF) cross sections while 63-66% of total fusion cross sections represent the complete fusion yields. The so observed suppression of fusion cross section is arising due to breakup of projectile in the entrance channel. As a result of breakup of projectile (^{9}Be), the projectile is partially absorbed by the target. The model calculations verify the magnitude of suppression factor as pointed out in literature.

According to Classical Dynamical Model as described in the code PLATYPUS [4], when a projectile is incident on the target with some initial energy E_{in} and orbital angular momentum L, the motion will be taken along a trajectory with definite distance of closest approach $R_{min.}(E,L)$. The trajectory of the projectile is tracked by solving the classical equation of motion in the presence of influence of mutual Coulomb and nuclear forces between the projectile and target. In code PLATYPUS, N be the number of breakup events sampled and N_o, N_1 and N_2 be the number of events with 0, 1 and 2 captured fragments respectively, the probability $P_0(E_0, L_0)$, $P_1(E_0, L_0)$ and $P_2(E_0, L_0)$ are defined as given below.

$$P_0(E_0, L_0) = P_{BU}(R_{\min})\tilde{P}_0$$

$$P_1(E_0, L_0) = P_{BU}(R_{\min})\tilde{P}_1$$

$$P_2(E_0, L_0) = [1 - P_{BU}(R_{\min})]H(L_{cr} - L_0) + P_{BU}(R_{\min})\tilde{P}_2$$

with H(x) as the Heaviside step function and L_{cr} as the critical partial wave for fusion. The first term in the expression of P_2 representing direct complete fusion (DCF) while the second as the sequential complete fusion (SCF). The cross sections are calculated by

$$\sigma_i(E_0) = \pi\lambda^2 \sum_{L_0}(2L_0 + 1)P_i(E_0, L_0)$$

where $\lambda^2 = \frac{h^2}{2\mu E_0}$ is the de-Broglie wavelength and μ is the reduced mass of the projectile-target system. The total interaction potential includes nuclear part, Coulomb potential and Centrifugal potential. For model calculations, the nuclear potential of Woods-Saxon type as defined by Broglia-Winther [5] has been used. The theoretical calculations obtained by using above mentioned potential within the consent of code PLATPUS are shown in Fig.1 and Fig. 2.

In Fig. 1, the incomplete fusion cross-section of ^{9}Be+^{197}Au as function of incident energy in laboratory frame of reference is shown. The incomplete fusion events are dominantly occurring due to breakup of the projectile in the force field of heavy target. The breakup effects are more peculiar at above barrier energies therefore; the above barrier fusion data get suppressed with reference to the predictions of coupled channel approach [8]. The Classical Dynamical Model considers the trajectory of the projectile-target system and the model calculations for ICF and CF events can be separately predicted. Among various inputs, the centroid and width of the Gaussian function that approximates the projectile's ground state radial probability distribution, are obtained by solving concerned Schrödinger wave equation and found to have values 1.91 and 2.1 respectively. The parameters of the breakup function is taken from [9] and are determined by using the experimental breakup probability information at two different values of R_{min}(or energy) in the vicinity of Coulomb barrier and found to be 10910 and 0.91fm-1 respectively [9]. Other parameters like radius, depth, range and diffuseness for target-projectile system, target-fragment 1(2) system and ICF channels are obtained by opting Broglia-Winther parameterization [5] of nuclear-nuclear potential.

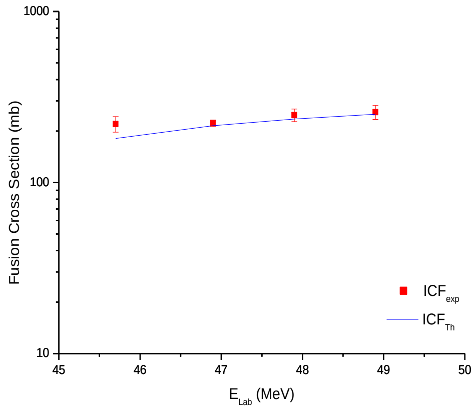

Fig.1, Fusion excitation function for ICF process for ^{9}Be+ ^{197}Au reaction is compared with the experimental data taken from Ref. [6].

In Fig.2, the CF cross sections are plotted as a function of incident beam energy for ^{9}Be+ ^{197}Au system and are compared with the corresponding experimental data taken from Ref. [6, 8] collectively. The experimental CF cross sections are very well reproduced at energies greater than and equal to approximately 1.1times V_B with V_B is the Coulomb barrier while for energies smaller than 1.1V_B, the calculations significantly under estimate the observations. The value of potential barrier in present projectile-target case comes out to be around 39.5-40.5MeV. At around barrier energies along with the quantum mechanical tunneling, various channel coupling effects play a very important role in the determination of fusion cross section. Since in the Classical Dynamical Model, which is implemented in the code, abovementioned effects responsible for sub barrier fusion enhancement are not taken into account and hence the experimental data are significantly underestimated in sub barrier energy region. Similar trend prevails for ICF originating from alpha absorption by the target is shown previously in Fig.1.

For ICF cross section, experimental data is available for above barrier energy only [7] which is very well reproduced in calculations performed by present model except for energy 45.7 MeV (i.e ≈1.14V_B). This is because in literature [7], it was found that ICF comes out to be ≈200-240mb for this energy which is same as obtained for energy 46.9 MeV. Further authors of Ref. [7] experimentally found that ratio of ICF to TF slightly decrease (i.e 42% to 38%) with increase in energy from 45.7 to 46.9 MeV while PLATYPUS based calculations were found it to be 36±1% in these energies.

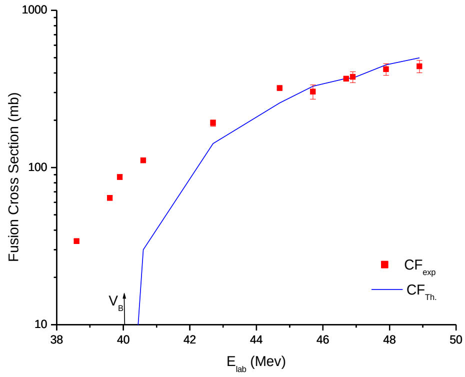

Fig.2, Fusion excitation function for CF process for ^{9}Be+ ^{197}Au reaction is compared with the experimental data taken from Ref. [6-7].

References

[1] L. F. Canto et al., *Phys. Rep.* **424**, 1 (2006).
[2] A. Diaz-Torres, D.J. Hinde, J.A. Tostevin, M. Dasgupta, L.R. Gasques, Phys. Rev. Lett. **98**, 152701 (2007).
[3] A. Diaz-Torres, J. Phys. G: Nucl. Part. Phys. **37**, 075109 (2010).
[4] A. Diaz-Torres, Comput. Phys. Comm. **182** 1100 (2011).
[5] W. Reisdorf, J. Phys. G: Nucl. Part. Phys. **20**, 1297 (1994).
[6] G. S. Li *et al.* Phys. Rev. C **100**, 054601 (2019).
[7] Malika Kaushik *et al.* Phys. Rev. C **101**, 034611 (2020).
[8] L. F. Canto *et* al. Phys. Rep. **596**, 1 (2015).
[9] R. Rafiei *et al.* Phys. Rev C **81**, 024601 (2010).