Reaction Cross Section of Heavy Projectiles Using Coulomb Modified Glauber Model

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Abstract. We investigated reaction cross section and inelastic collisions of the wide number of projectile and target nuclei using the Coulomb Modified Glauber Model (CMGM). The total reaction cross sections were calculated with and without accounting for in-medium effect for various heavy projectiles such as $^{56}Fe_{26}$, $^{84}Kr_{36}$, $^{132}Xe_{54}$, $^{197}Au_{79}$ and $^{238}U_{92}$ that interact with Nuclear Emulsion Detector's (NED) nuclei at incident energies at around 1 GeV/n. The calculated average values of reaction cross section are compared with the corresponding experimental data.

1. Introduction

In recent years, heavy ion collisions at low and high energies have become a subject of great interest and activity. The investigation of such interactions provides information regarding geometry of collision in both cases of symmetric and asymmetric collisions [1-2]. Nuclear emulsion detector is a widely used one of the oldest particle detectors for the investigation of the nuclear interactions because of the superb spatial resolution and 4π acceptance [3-5]. In heavy ion collision, one of the most important physical quantities is the total reaction cross section, which is useful in the study of nuclear reactions and nuclear models [6]. The high energy nucleus - nucleus (A-A) and hadrons-nucleus (h-A) collision are effectively treated in the framework of the Glauber Model (GM) [7]. It considers the nucleus- nucleus (A-A) collision in terms of the nucleon- nucleon (N-N) interactions with given nuclear density distributions [6-7]. At high energies, the model successfully described the reaction cross section of heavy ion collisions and further, this model was elongated to the low energies by taking into effect of the Coulomb field. This approach is called the Coulomb Modified Glauber Model (CMGM) [8-9]. In the present work, we are interested in the shower particles multiplicity (N_S), which is admixture of the Pions and Kaons produced as a result of the interaction of different projectiles with the emulsion nuclei. Here we apply the CMGM model to calculate the total reaction cross sections with and without accounting for in-medium effect for different projectiles $^{56}Fe_{26}$, $^{84}Kr_{36}$, $^{132}Xe_{54}$, $^{197}Au_{79}$ and $^{238}U_{92}$, which interact with different elements of the emulsion detector nuclei such as H, CNO, Ag and Br at incident energies at around 1 GeV/n. The calculated values of the total

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reaction cross section are compared with corresponding experimental data. Additionally, we have calculated the average number of projectile participants (P_P), target participants (T_P), binary collisions (B_C) and shower particles (N_S). We used NIKFI (BR-2) and ILFORD (G5) emulsion plate's chemical composition in calculation.

2. Formalism of Coulomb Modified Glauber Model

According to the framework of the Glauber Model, the total reaction cross section can be written as [9]

$$\sigma_R(mb) = 2\pi \int [1 - T(b)] b.db. \tag{1}$$

Where $T(b) = \exp[-\chi(b)]$ is defined as the transparency function. For the Gaussian density distribution of colliding nuclei one can obtain the respective phases χ(b) as done in ref. [8].

$$\chi_{PT}(b) = \left(\frac{\pi^2 \rho_P(0) \rho_T(0) a_P^3 a_T^3}{10\left(a_P^3 + a_T^3 + r_0^2\right)} \bar{\sigma}_{NN} \right) \exp\left(-\frac{b^2}{a_P^2 + a_T^2 + r_0^2} \right). \tag{2}$$

Where $\rho_i(0)$ and a_i are the parameters given in Table II of ref.[8],

Here, $\bar{\sigma}_{NN}$ are the energy dependent N-N cross sections of the proton-proton (σ_{pp}) or neutron-neutron (σ_{nn}) and neutron-proton (σ_{np}) interactions presented in ref. [11] in the form as,

$$\bar{\sigma}_{NN} = \frac{\left(Z_P Z_T + N_P N_T\right)\sigma_{pp} + \left(Z_P N_T + Z_T N_P\right)\sigma_{np}}{A_P A_T} \tag{3}$$

$$\sigma_{pp} = \sigma_{nn} = \left(13.73 - 15.04\beta^{-1} + 8.76\beta^{-2} + 68.67\beta^4\right) \times \frac{1.0 + 7.772 E_{lab}^{0.06} \rho^{1.48}}{1.0 + 18.01\rho^{1.46}}. \tag{4}$$

$$\sigma_{np} = \left(-70.67 - 18.18\beta^{-1} + 25.26\beta^{-2} + 113.85\beta\right) \times \frac{1.0 + 20.88 E_{lab}^{0.04} \rho^{2.02}}{1.0 + 35.86\rho^{1.90}}. \tag{5}$$

Where the last factors are the in-medium corrections for the nuclear nucleons. The coulomb modified corrections of the straight line trajectory of motion is achieved by exchange the impact parameter b by b´ [8],

$$b' = \frac{\eta + \sqrt{(\eta^2 + k^2 b^2)}}{k}, \qquad \eta = \frac{Z_P Z_T e^2}{\hbar v}. \tag{6}$$

These calculated reaction cross sections are used in the calculation of projectile participants (P_P), target participants (T_P) and binary collision (B_C) from the following geometrical relation [1].

$$< P_P > = \frac{A_P \sigma_{P A_T}}{\sigma_{A_P A_T}}, \tag{7}$$

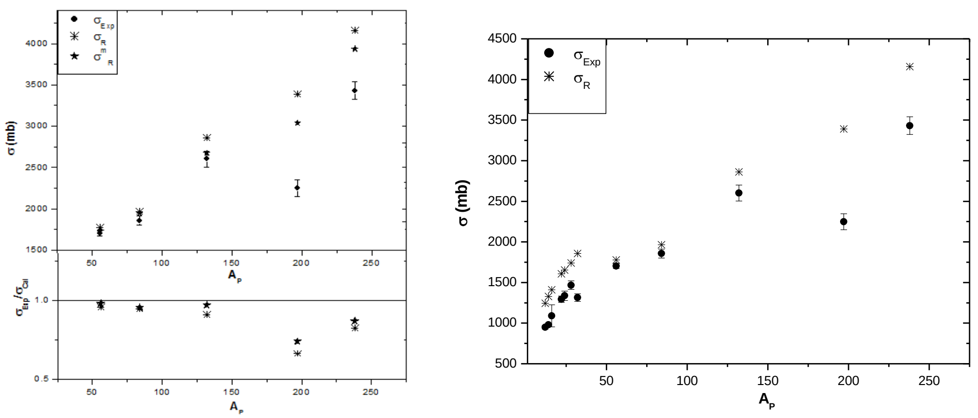
$$< T_P >= \frac{A_P \sigma_{PA_P}}{\sigma_{A_P A_T}}, \quad (8)$$

$$< B_C >= \frac{A_P A_T \sigma_{nn}}{\sigma_{A_P A_T}}. \quad (9)$$

Where A_P and A_T are the projectile and target masses, respectively.

3. Results and Discussions

Calculations of average values of the total reaction cross sections of the projectiles $^{56}Fe_{26}$, $^{84}Kr_{36}$, $^{132}Xe_{54}$, $^{197}Au_{79}$ and $^{238}U_{92}$ with emulsion nuclei at ~1 GeV/n have been performed using eqs. (1) - (5). Where we used nuclear matter density $\rho = 0$ and $\rho = 0.17$ fm^{-3}, respectively. The respective reaction cross sections without and with nuclear medium effects are represented as σ_R and σ_R^m as shown in fig.1 (a, b).



(a) (b)

Fig.1. (a) The reaction cross section calculated with and without in-medium effect and corresponding experimental data for projectiles $^{56}Fe_{26}$, $^{84}Kr_{36}$, $^{132}Xe_{54}$, $^{197}Au_{79}$ and $^{238}U_{92}$ at around 1 GeV/n. (b) Calculated reaction cross sections σ_R values for different projectiles [14].

Figure.1 (a) displays the calculated total reaction cross sections with and without nuclear medium effect in comparison with the corresponding experimental data. From the figure 1 (a) one sees that the calculated reaction cross sections with accounting for in-medium effect are better agreement with the data than those for free nucleons. Without these effects, the reaction cross sections σ_R show fairly good agreement with experimental ones for the projectiles $^{56}Fe_{26}$, $^{84}Kr_{36}$, $^{132}Xe_{54}$ and disagreement with the projectiles $^{197}Au_{79}$ and $^{238}U_{92}$. While the calculated reaction cross sections with in-medium effect σ_R^m show good agreement with projectiles $^{56}Fe_{26}$, $^{84}Kr_{36}$, $^{132}Xe_{54}$ and still disagreement with projectiles $^{197}Au_{79}$, and $^{238}U_{92}$. In the same figure, we have also shown the ratio of $\sigma_{Exp}/\ \sigma_{Cal}$ as a function of A_P, which demonstrates that the calculated reaction cross section values are closer to the experimental values for projectiles $^{56}Fe_{26}$, $^{84}Kr_{36}$, $^{132}Xe_{54}$ except for the $^{197}Au_{79}$ and $^{238}U_{92}$. Also calculated reaction cross section σ_R values are compared with the other projectiles taken from ref. [14]. From the figures, one may see that the calculated reaction cross sections with in-medium effects show good agreement with the experimental values within the experimental error for different projectiles. The reaction cross section values strongly depend on the projectile mass number (A_P). From eqs. (7) - (9), we have calculated the average number of projectile participants (P_P), target participants (T_P) and binary collision (B_C) for reactions with the emulsion nuclei using the CMGM model. Further the calculated average values of participants and binary collision are used in the calculation of shower particle (N_S) multiplicities. The estimated amount of shower particle multiplicities and corresponding experimental values are given in table 1.

Table 1. The calculated average values of the shower particle multiplicities (N_S) in framework of the CMGM model and corresponding experimental data are tabulated.

Reaction Systems	$\langle n_s \rangle^{Exp}$	Calculation with nuclear medium effect			Calculation without nuclear medium effect		
		$\langle n_s \rangle$ (P_P+T_P)	$\langle n_s \rangle$ (B_C)	$\langle n_s \rangle^{theory}$	$\langle n_s \rangle$ (P_P+T_P)	$\langle n_s \rangle$ (B_C)	$\langle n_s \rangle^{theory}$
^{56}Fe-Em	-	21.47	27.88	10.26	21.93	28.44	09.64
^{84}Kr-Em	13.14±0.39 [15]	27.39	37.56	14.29	28.11	38.64	13.05
^{132}Xe-Em	17.40±0.70 [16]	29.82	43.85	15.90	30.08	43.66	14.83
^{197}Au-Em	16.43±3.43 [17]	35.23	54.43	19.59	39.13	60.45	20.24
^{238}U-Em	-	34.93	55.26	20.48	36.11	56.90	19.49

It is clear from the table 1, that the calculated average values of the projectile and target participants and binary collision are increases with increasing colliding nuclei mass number in both cases. Similarly, the estimated numbers of the participants are smaller than binary collision, which indicates that most of the shower particles are coming from the binary collision for all above reactions. From the table 1, one can also observed that the average number of shower particles continuously increases with increasing projectile mass number, which shows that the produced shower particles show strong dependence on the projectile mass number. It is also found that in both the cases i.e. with and without nuclear effects, CMGM model successfully reproduced the shower particles multiplicities for projectiles having A = 56 → 238.

4. Conclusions

In conclusion, using the CMGM model with and without accounting for the nuclear in-medium effect, we have calculated the total reaction cross section for projectiles $^{56}Fe_{26}$, $^{84}Kr_{36}$, $^{132}Xe_{54}$, $^{197}Au_{79}$ and $^{238}U_{92}$ with nuclear emulsion nuclei at around 1 GeV/n. These calculated values are compared with the available experimental data. Without the nuclear in-medium effect the CMGM model leads to good agreement with experimental values within statistical error for projectiles $^{56}Fe_{26}$, $^{84}Kr_{36}$, $^{132}Xe_{54}$ and it shows disagreement with projectiles $^{197}Au_{79}$, $^{238}U_{92}$. It should be recommended that the proposed model should be modified for the heavier mass of projectiles. The total reaction cross section values increase with increasing projectile mass number. We have also calculated the average number of projectile and target participants, binary collisions and shower particles value considered with (and without) nuclear in-medium effect. The average number of participants and binary collisions are increased with increasing the projectile mass number. Present calculated shower particle multiplicities are in good agreement with the respective experimental values within the errors for all considered reactions. The produced shower particles value shows strong dependence on the projectile mass number.

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