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Study of The Total Reaction Cross Section of 17.0 MeV/N $^{132}Xe+^{238}U$ Heavy Ion Interactions

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Abstract

We have studied heavy ion nuclear interactions of 17.0 MeV/N $^{132}Xe+^{238}U$ using muscovite mica as Solid State Nuclear Track Detector (SSNTD). Experimental reaction cross section has been determined by two independent methods. Theoretical reaction cross section has been calculated by a classical formula taking into account the energy dependence of the nuclear radius parameter. The cross section determined in the present work has been compared with those at two other energies for the same reaction.

Introduction

One of the fundamental quantities required for characterizing a nuclear reaction is the total reaction cross section, σ_R. It has been studied extensively both theoretically and experimentally for many years [1-6]. The nuclear cross section provides information about the radii and transparency of nuclei and gives clues regarding their structure. The nuclear cross section is predicted by several nuclear models, including the optical and absorption models [7]. A parameter-free energy-dependent geometric model for the nuclear absorption cross section has been derived from the microscopic formulation [8]. This model is characterized by energy-dependent effective radius. As the relative energy of nucleus-nucleus collisions increases well beyond the interaction barrier, the nuclear reaction mechanisms which contribute to the total reaction cross section become increasingly complex [9]. At projectile energies above 10 MeV/N, mean-field processes such as complete fusion and simple two-body transfer reactions gradually diminish, while the probability of fragmentation [10-11], and pre-compound emission of nucleons [12-13] and heavier fragments, grows rapidly [14].

Theoretically, there are two kinds of approaches for calculating the reaction cross-section. The low-energy theory is based on an interaction potential such as the Bass model [4]. In this model the interaction radius is obtained empirically by fitting the experimental data. The second kind of theory is the high-energy microscopic Glauber multiple-scattering theory which is based on individual nucleon-nucleon (N-N) collisions in the overlap volume of the colliding nuclei [15]. But, most Glauber-type models present difficulties in investigating the dynamics and quantum effects on the total reaction cross section [16].

In a heavy ion reaction, theoretical reaction cross section (σ_{Theo}) which is a function of radius of interaction $R_{int.}$, centre-of-mass energy E_{cm}, and interaction potential is normally determined by the classical model allowing for Coulomb deflection of the orbits:

$$\sigma_{Theo.} = \pi R_{int}^2 [1 - (V/E_{cm})], \tag{1}$$

where

$$V = \text{Coulomb Potential} = Z_P Z_T e^2 / R_{int,} \tag{2}$$

and

$$R_{int.} = r_0 (A_P^{1/3} + A_T^{1/3}), \tag{3}$$

and r_o being a radius factor which depends weakly on the energy of the projectile. In the above equations $(Z_P e)$, A_P are the charge and mass number of the projectile while $(Z_T e), A_T$ are those for the target nucleus.

In this work we have determined the experimental reaction cross section of heavy ion nuclear interactions, 17.0 MeV/N $^{132}Xe +^{238}U$, by two independent methods, and compared it with theoretical cross section based on eq.(1).

Experimental Procedure

The target ^{238}U was deposited on mical detector sheets in the form of UF_4 at the Institute of Nuclear Chemistry, Marburg, Germany. The thickness of the target material on each detector was determined using a sensitive electronic balance. The samples were irradiated prependicular to their surface with 2×10^6 $^{132}Xe\ ions/cm^2$, having 17.0 MeV/N energy, at the UNILAC accelerator of GSI, Darmstadt, Germany.

After the irradiation, the target material was dissolved off with HNO_3 and the mical samples were etched with 40 $\% H_2F_2$ at room temperature for 80 minutes.

Results and Discussion

Among the binary data, the elastic events were separated firstly on the basis of angular criterion valid for elastic scatterig, and secondly, on Total Kinetic Energy Loss (TKEL) criterion. To apply the second criterion, we used an empirical range-energy reltionship having fifteen fitted coeffiients as described in detail in ref. [17]. As we expect to have zero TKEL in the case of pure elastic events, a Gaussian-Fitted data at (0 ± 50) MeV in the energy spectrum of the binary events, shown in Fig. (1), represent elastic set of the binary events. The value of 50 MeV used as standard deviation of the Gaussian distribution for TKEL is, in fact, due to the standard errors encountered in the measurements of the track parameters [18]. A total of 288 events are within the bin of (-150$<$TKEL$<$150) MeV. We have designated only those events as pure elastic events which obey both the criteria valid for elastic events. We could, therefore, select 111 events as final set of pure elastic events out of 515 total binary events.

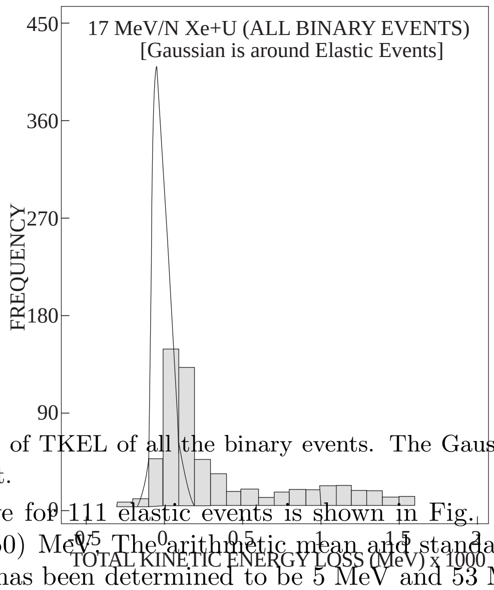

Figure 1. Distribution of TKEL of all the binary events. The Gaussian fit around (0 ± 50) MeV represent elastic set.

The TKEL curve for 111 elastic events is shown in Fig. (2). The Gaussian has been fitted with (0 ± 50) MeV. The arithmetic mean and standard deviation for TKEL of these elastic events has been determined to be 5 MeV and 53 MeV, respectively.

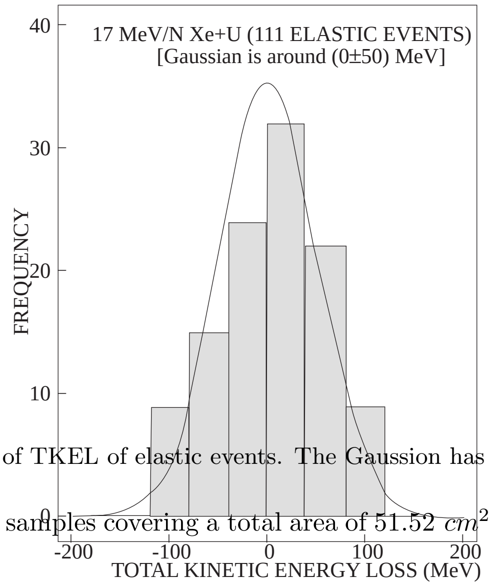

Figure 2. Distribution of TKEL of elastic events. The Gaussion has been fitted with (0 ± 50) MeV

We scanned four samples covering a total area of 51.52 cm^2 and recorded the data, as given in Table 1.

Table 1. Statistics of events of various multiplicity. E and IE stand for elastic and inelastic events whereas D and ID stand for direct and indirect events.

Total (806) Observed Events								
Binary			Three-Pronged			Four-Pronged		
E	IE	Total	D	ID	Total	D	ID	Total
111	404	515	93	178	271	6	14	20

We have used the inelastic events of different multiplicities and employed the following formula for the determination of experimental partial and total reaction cross sections:

$$\sigma = \frac{\sum_i R_i \sum_i \alpha_i}{\sum_i [\alpha_i N(\rho t)_i] \sum_i \phi_i a_i} (cm^2), \tag{4}$$

where R_i are the total number of direct and indirect events in the ith sample, ϕ_i is the fluence of the projectiles $(\sharp/cm^2)$, and N is the number of the target nuclei per mg of UF_4 and $(\rho t)_i$ is the specific thickness of the target (mg/cm^2). The sum runs over the number of samples.

The parameters used for the calculation of reaction cross sections are given in Table (2) and the experimental results of partial and total cross sections of 17.0 MeV/N $^{132}Xe +^{238} U$ reaction are given in the Table (3).

Table 2. Parameters used for calculation of reaction cross section

Scanned area (cm^2)	Average Target Thickness (mg/cm^2)	Fluence for each sample ($\sharp/cm^2$)	Total Observed Events			
			Two - pronged	Three - pronged	Four - pronged	Total
51.52	1.1878	2×10^6	404	271	20	695

Table 3. Partial and total experimental reaction cross sections

$\sigma_2(mb)$	$\sigma_3(mb)$	$\sigma_4(mb)$	$\sigma_{exp}(mb)$
1720±220	1155±150	85±20	2960±360

The elastic events were used to calculate experimental reaction cross section employing the Blair‘s quarter point recipe [19]. The quarter point angle $(21.25\pm4)^\circ$ gave the cross section of (5460$\pm$1600)mb.

The value of theoretical reaction cross section σ_{Theo} depends strongly upon the value of radius of interaction and hence on radius factor which can be determined only empirically [8]. It has been observed that at energies higher than 10.0 MeV/N, the values which are usually used for r_0 ($>$1.3 fm) are no more valid. The value of r_0 quoted in literature, varies from 1.2 [8] to 1.3 [7]. For the nuclei with A$>$16 amu involved in the interaction at energies above 10.0 MeV/N, a value of r_0=1.25 has been suggested [8,16].

We have therfore used the value of $r_0 = (1.25\pm0.05)$ fm in Eq., (3) and determined the reaction cross section, which comes out to be (4070$\pm$420) mb.

Theoretical cross section, calculated with the alue mentioned aboe, is in reasonable agreement with the one determined experimentally (Table 4). Hence the value of r_0, which is energy-dependent seems to be appropriate in our energy domain.

The comparison of the reaction cross sections obtained from two independent experimental procedures and from theoretical calculations are given in Table 4.

Table 4. Comparison of Experimental and theoretical cross section

Cross Section (mb)		
Experimental		Theoretical ($r_0 = 1.25 \pm 05$)
using inelastic events	using elastic events	
2960±360	5460±1600	4070±420

The comparison shows that the reaction cross section determined experimentally from the inelastic events has lower standard error and is , therefore, more reliable than the one obtained experimentally from the quarter point angle. The later has more relative error due to the paucity of elastic events which cause problems in plotting the ratios of the experimental to Rutherford cross sections in sufficiently narrow bins of scattering angles. Since the theoretical cross section also cannot be determined with 100% accuracy, we conclude that the cross section obtained experimentally from the inelastic data is reasonable. Since, it is the sum of the partial cross sections, the cross sections for two, three and four pronged events exhaust the total reaction cross section which are given in the ratio of 58,39 and 3 respectively.

In the end we compare the values of cross sections for the same reaction at two other energies in table (5) to see the trend of the cross section with respect to the increase in energy.

Table 5. Trend of the cross section with respect to energy

Energy (MeV/N)	σ_{exp}(mb)	σ_{Theo}(mb)	Reference
8.5	2780 ±250	2749	20
14.0	3650±350	3428	21
17.0	2960±360	4070	

The rise in crosss section with respect to energy is expected theoretically. However, our experimental value at 17 MeV/N is lower than expected value which is related to the problem of correctly resolving the inelastic binary events.

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