Investigation of Heavy-ion Induced Fusion Reactions at Near and Above Barrier Energies

Maninder Kaur*
Department of Physics, Panjab University, Chandigarh - 160014, INDIA.
** email: manisaini153@gmail.com*

Introduction

Understanding the role of the dynamical effects on fusion dynamics is an important topic of research due to the complex nature of the process involved. This thesis work shows the importance of entrance channel mass asymmetry on the reaction dynamics using light particles evaporation spectra, spin distribution and cross-section measurements as probes. This work is motivated from the studies of various light particle evaporation spectra existing in the literature. These studies have established that the fusion dynamics of asymmetric and symmetric target-projectile combination populating the same compound nucleus (CN) is different. While the light particle spectra for the asymmetric systems could be explained by using the statistical model, the spectra for the symmetric systems were having deviations from the statistical model predictions [1,2]. These deviations were explained on the basis of the calculations involving the modification of important ingredients of the statistical model codes such as by using spin dependent level density or lower values of level density parameter and considering the presence of dynamical effects.

Motivation of the present thesis work

Motivated by the studies showing the requirement of modification of the level density to explain the deviations observed in the symmetric systems, we have carried out a systematic study of the level density parameter, *'a'*, for different systems in the mass region A~50-110, populated through the asymmetric target-projectile combinations. This study indicates that the deviations in the experimental spectra for the symmetric systems may not always due to the incorrect value of the level density parameter and some other ingredient of the statistical model may have to be modified to account for the deviation observed in the symmetric systems [3]. Moreover most of the existing measurements of the light particles evaporation spectra are inclusive measurements, so we have performed the ER-gated measurements of α-particle, neutron and proton evaporation spectra for the relative symmetric systems ^{28}Si+^{45}Sc and ^{32}S+^{45}Sc populating ^{73}Br and ^{77}Rb respectively. Since the dynamical calculations for different systems existing in the literature indicate that the maximum values of *l* contributing to the fusion are lesser than the asymmetric system, so it is interesting to see how the various partial waves contribute to the fusion process. To investigate this we have performed the evaporation residue (ER) spin distribution (SD) and the cross-section measurements for two systems (^{16}O+^{64}Zn and ^{32}S+^{48}Ti), differing in the entrance channel mass asymmetry but populating the same CN, ^{80}Sr.

Experimental details

The experiments were carried out using Heavy ion reaction analyzer (HIRA) [4] at IUAC, New Delhi. Pulsed beams of ^{16}O with repetition rate of 2 μs, in the energy range from 46 to 91.9 MeV and ^{32}S with repetition rate of 1 μs, in the energy range from 87 MeV to 125 MeV and ^{28}Si at 125 MeV were provided by 15UD pelletron accelerator. The thickness of the targets ^{64}Zn and ^{48}Ti was about 500 μg/cm^2 and of ^{45}Sc was about 520 μg/cm^2. Two silicon surface barrier detectors (SSBD) were mounted at ±25^o with respect to beam direction at a distance of 10 cm from the center of the target. The ERs were separated from the other contamination by HIRA and were detected at the focal plane using a MWPC. The charged particle spectra were measured at 40^o using the telescope detector arrangement and the neutron spectra were measured at 90^o w.r.t. beam using the NE213 scintillator detector. For the cross-section measurements, the transmission efficiency of HIRA was measured using HPGe detector mounted at the target chamber at a distance of 2 cm. The SD measurement was performed using the BGO array [5].

Data Analysis and Results

Light particle Evaporation spectra measurement

ER-gated exclusive spectra were obtained for both the systems. The shapes of both the inclusive and exclusive spectra were found to be same. The theoretical calculations were performed out using the CASCADE code. These measurements also showed the non-fusion of higher partial waves. Through the simultaneous analysis of the α-particle, proton and neutron spectra, a consistent picture of the fusion dynamics has also been developed. [6]. Further, the non-fusion of the *l* values can be better revealed through the cross-section and spin distribution measurements. So we have explored these probes to study the fusion dynamics of asymmetric system ^{16}O+^{64}Zn and symmetric ^{32}S+^{48}Ti.

Cross-section measurement

The cross-section measurements were performed for center of mass energies ranging from 48 MeV to 73.5 MeV for ^{16}O+^{64}Zn and 52 MeV to 75 MeV for ^{32}S+^{48}Ti. The cross-section measurement for ^{16}O+^{64}Zn at low energies was performed earlier by Gomes *et al.* [7]. The transmission efficiency of HIRA was determined by the coincidence γ-ray method and using TERS code [8]. The experimental cross-sections thus obtained were compared with the theoretical calculations performed using the CDEFF code as well as the TDHF [10] calculations. For both the systems the experimental cross-sections were in agreement with the theoretical calculations. However the evolution of the x-component of the quadrupole deformation calculated using the TDHF calculations indicated the presence of the dynamical effects for both the systems at the highest energies.

Spin Distribution measurement

To understand this anomaly, we have also performed the ER-gated SD measurements for ^{16}O+^{64}Zn for the center of mass energy range 53.3 MeV to 73.5 MeV and ^{32}S+^{48}Ti for the center of mass energy range 57 MeV to 75 MeV. Van der Werf's prescription [10] was used for unfolding the γ-multiplicity distributions from experimental γ-fold distributions. *γ*-multiplicity distributions were converted to spin distribution by assuming that average spin carried away by each non-statistical γ-ray is 1.6. This value was extracted by looking into the level schemes of the ERs. Corrections due to angular momenta carried by evaporated particles and statistical γ rays were also incorporated. Using the experimental cross-sections obtained from the earlier experiment, the spin distributions of the CN were obtained. These were compared with spin distribution generated by fitting the experimental cross-sections using CCDEF. It was observed that for the symmetric system, the contribution of the higher partial waves towards fusion goes on decreasing with the increase in energy. For the asymmetric system as well, this effect was visible at the highest energies. These observations were not reflected in the cross-section measurements as cross-sections correspond to the zeroth moment of the spin distribution, so there can be many shapes of the spin distribution, reflecting very different physical processes involved, but yielding the same fusion cross-section. The experimental spin distributions, for ^{32}S+^{48}Ti at E_{lab} = 125 MeV [1], were give as an input to the PACE code and the α-particle spectrum thus generated was found to be in excellent agreement with experimental spectrum. From the present study, it has been observed that in the interpretation of Light particle evaporation spectra through statistical model, along with the different parameters the experimental fusion cross-section and the spin distribution must be taken into account.

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