STUDY OF SOME HEAVY-ION INDUCED REACTIONS BELOW 7 MeV/NUCLEON

*Tauseef Ahmad
Department of Physics, AMU, Aligarh. -202002, INDIA
** email: tau_ad @rediffmail.com*

The main purpose of the thesis is to shed light on the heavy-ion (HI) reaction mechanisms involved in the formation of the observed evaporation residues. The thesis explores the dynamics of HI induced reactions (mainly complete and incomplete fusion) by measuring the excitation functions(EFs) for a large number of residues produced in ^{12}C + ^{93}Nb, ^{12}C + ^{52}Cr and ^{16}O + ^{115}In systems at energies near and well-beyond the Coulomb barrier. The measured EFs for various residues in these systems have been compared with the statistical model code PACE 2, based on Hauser-Feshbach theory. In order to show the difference between our data and the earlier reported values (in the case of ^{12}C+ ^{93}Nb system) we have also compared our new measurements with the ALICE-91 whereas the earlier researcher has compared the results with old version ALICE. Further, to separate the relative contributions of the complete and the incomplete fusion in ^{12}C+^{93}Nb system, the Recoil Range Distributions (RRDs) of several residues have also been measured.

From the point of view of Physics, the different reaction mechanisms of HI collisions and their dependence on the available laboratory energies are of great interest. Ever since Incomplete Fusion (ICF) reactions in HI collisions have been observed at relatively low bombarding energies, the study of mechanisms of these reactions has gained momentum. Moreover, the ICF reactions are considered to be a promising route to populate high spin states in heavy residues using moderate heavy–ion beams (A ≤16) even at low bombarding energies. In view of all these developments the study of the ICF dynamics may provide key parameters to determine optimum irradiation conditions for the production of radioactive ion beams (RIBs). In order to explain the ICF reactions, several dynamical models, such as the Sum-rule model, the Break- up Fusion (BUF) model, the Promptly Emitted Particles (PEPs) model etc., have been proposed. However, none of these models has succeeded in explaining all the features of ICF reactions at energies below 10 MeV/ nucleon. Hence the ICF reactions continue to be an active area of investigation. Such an investigation may be fruitful if it aims at systematizing the ICF dynamics by using the precise experimental data covering a wide range of the periodic table and energies. In this context, an accurate measurement and analysis of the EFs of nuclear reactions are of immense importance. It is the shape of the EFs, which reveals the reaction mechanism. For instance, the slowly descending tail of the EFs is a direct signature of the Pre-equilibrium emission. A comparison of experimentally measured EFs with the theoretical model calculations indicates an agreement and /or disagreement, which serve as a clue for the understanding of reaction mechanism of CF and/or ICF. This is not the only criterion we have used for determining the CF and/or ICF mechanism but RRDs (in the case of ^{12}C+^{93}Nb system) have also been used as a criterion to characterize the aforesaid mechanisms.

Apart from being beneficial to the area of HI reactions, the study of the EFs is useful from the point of view of nucleo-synthesis. Moreover, there is a growing need of a comprehensive understanding of EFs so that the production of isotopes used in medicine may be maximized. Besides, the values of EFs play a significant role in the study of thin layer activation (TLA) technique. In addition to these applications, the EFs are also in demand for the development of accelerator driven subcritical reactors popularly known as energy amplifiers.

In order to study HI reaction mechanism, the experiments were carried out at Inter-University Accelerator Centre (IUAC), New Delhi, India. In our experiments three different types of targets viz., ^{93}Nb, ^{52}Cr and ^{115}In were prepared either by rolling machine or by the vacuum–evaporation technique. The Al foils, prepared by rolling machine, were used as energy degraders in the EF measurements. To characterize the thickness of each target, we used gravimetry for ^{93}Nb and the alpha transmission method for ^{52}Cr and ^{115}In. Three different stacks of samples were irradiated for different time spans keeping in view the half-lives of the yields, the melting point of the target element and also the thickness of the targets. After the irradiation, the exposed stack was taken out of General Purpose Scattering Chamber (GPSC) using In-vacuum Transfer Facility (ITF). Subsequently, the gamma–ray spectra of activated target foils were recorded by counting the target and catcher foils together using a high resolution (2 keV for 1332 keV γ ray of ^{60}Co) high purity Ge (HPGe) detector of 100 cm^3 active volume coupled to a PC based multichannel analyzer employing FREEDOM software. The dead time for counting was kept less than 10% by adjusting the target detector separation in these measurements and proper account of the dead time was taken in the calculations. Various peaks observed in these spectra were assigned to different reaction residues on the basis of their characteristic energy of gamma-lines as well as measured half-lives. The activation technique, which is popular for its sensitivity, selectivity and simplicity, was employed in these measurements. The RRDs of several residues at $\approx$ 80 MeV incident beam energy have also been measured using recoil catcher technique and off-line gamma ray spectrometry. In order to measure the RRDs, the yield was calculated by way of dividing the cross-section by thickness of each catcher foil.

The experimentally measured EFs for ^{12}C and ^{16}O induced reactions were compared with the theoretical predictions made on the basis of model code PACE2. By way of such a comparison, we have extracted some important information about the complete and the incomplete fusion process in heavy–ion reactions. The considerable enhancements of the experimentally measured EFs for some reactions clearly indicate that these reaction channels are populated not only by the complete fusion but also through the incomplete fusion process. The analysis of RRDs confirms the presence of contributions from the ICF reactions. The range distributions clearly show three separable components, which are attributed to complete fusion of ^{12}C, incomplete fusion of ^{8}Be and incomplete fusion of ^{4}He, with the target. The determined relative contributions (shown in %) of the CF and the ICF indicate that the ICF plays an important role in the population of different reaction products involving direct α-cluster and Be emission at energies below 7 MeV/nucleon. Moreover, the direct reactions are also found to be significant in the population of radionuclides ^{93}Mo^{m} and ^{92}Nb^{m}.

The present thesis consists of five chapters. In the first chapter, a general introduction of HI induced reactions and related topic is presented. A brief review of the work reported in this thesis is also given in this chapter. The second chapter focuses on the essential experimental details for studying HI reactions at IUAC, the derivation of cross-section formulation and the sources of error in the measured physical quantities. The measurements of EFs for thirty reactions namely ^{93}Nb (C, 2n)^{103}Ag, ^{93}Nb (C, 3n) ^{102}Ag, ^{93}Nb(C, 4n) ^{101}Ag, ^{93}Nb(C, p3n)^{101}Pd, ^{93}Nb (C, p4n)^{100}Pd, ^{93}Nb(C, p5n)^{99}Pd, ^{93}Nb(C, 2p2n)^{101}Rh , ^{93}Nb(C, αn)^{100}Rh,^{93}Nb(C,α2n)^{99}Rh,^{93}Nb(C,αp3n)^{97}Ru,^{93}Nb(C,αp5n)^{95}Ru,^{93}Nb(C,2αn)^{96}Tc,^{93}Nb(C,2α2n)^{95}Tc,^{93}Nb(C,2α3n)^{94}Tc,^{93}Nb(C,2αp3n)^{94}Mo^{m},^{93}Nb(^{12}C,^{13}C)^{92}Nb^{m} , ^{52}Cr (C, 2n) ^{62} Zn, ^{52}Cr (C, p2n) ^{61}Cu, ^{52}Cr (C, p3n) ^{60}Cu, ^{52}Cr(C,α3n) ^{57}Ni, ^{52}Cr(C,α4n) ^{56}Ni, ^{52}Cr (C, α p3n) ^{56}Co, ^{52}Cr (C, α p4n) ^{55} Co, (C, α3pn) ^{56} Mn,^{115} In (O,p3n)^{127}Ba, ^{115} In (O,p4n)^{126}Ba , ^{115} In (O, α)^{127}Cs, ^{115} In (O,α2n)^{125}Cs, ^{115} In (O, αp3n)^{123}Xe, and ^{115} In (O, αp5n)^{121}Xe have been enumerated in the third chapter. The essential input parameters for evaluating EFs using computer codes ALICE-91 and PACE2 are discussed in the fourth chapter. The last chapter contains the experimental results, the analysis of the experimental results with the above-mentioned codes.