Chapter 7

Summary and conclusion

The inclusive double differential cross-sections for IMFs having atomic number, \(3 \leq Z \leq 5\), emitted in the reactions involving both \(\alpha\)-cluster and non \(\alpha\)-cluster systems (a) \(^{16}\text{O} (117, 125, 145 \text{ and } 160 \text{ MeV}) + ^{12}\text{C}\) and (b) \(^{11}\text{B} (64 \text{ MeV}) + ^{28}\text{Si}, ^{12}\text{C} (73 \text{ MeV}) + ^{27}\text{Al}\) and \(^{12}\text{C} (77 \text{ MeV}) + ^{28}\text{Si}\), have been measured in two separate experiments [(a) and (b)]. For the system (a), the energy distributions of all fragments at all incident energies were single peaked, having nearly Gaussian shapes with their centroids at the expected kinetic energies corresponding to the binary break up obtained from the Viola systematics corrected by the corresponding asymmetric factors. The energy distributions of the fragments emitted from the systems (b) were found to have two peaks, one originating from equilibrated source, identified as FF process, and, the other from non-equilibrium source, DI process; each of these peaks is fitted with a separate Gaussian. Characterisation of the equilibrium component of fragment spectrum has been done in various ways. The angular distributions \((d\sigma/d\Omega)_{c.m.}\) were found to follow \(1/\sin\theta_{c.m.}\) dependence in all cases. It has been observed that for each fragment, at all bombarding energies, the average \(Q\)-value is independent of emission angle, which suggests that the fragments are emitted from a completely equilibrated source at all the incident energies considered here. Total elemental cross-section for the fragments Li to B have been estimated from the experimental distributions and the same have been compared
with the statistical model predictions. At all incident energies, a significant enhancement in the yield of the fragment B have been observed over the theoretical predictions of CASCADE and EHFM calculations for the α-cluster system (a). The yield of the fragments Li and Be are in good agreement with the theoretical predictions of the statistical model code CASCADE, though they are underpredicted by EHFM calculations. However, the magnitude of mismatch increases progressively from Li to B, which clearly indicates increasing additional contributions from other reaction mechanism or possible enhancement to the energy damped yield near the entrance channel configuration. The above observation is consistent with the fact that the NOC value for this system is much smaller than those for other two nearby systems - which is indicative of the formation of an orbiting dinuclear complex in $^{16}\text{O}+^{12}\text{C}$ at the energies studied here. However, the total angle integrated yields of the equilibrium fragments in the reactions (b) are in fair agreement with EHFM predictions which confirm their compound nuclear origin; even the yields of FF fragments emitted from α-cluster system, $^{12}\text{C}+^{28}\text{Si}$, also match with EHFM predictions. It is interesting to note here that a previous study on fragment decay from the same system ($^{40}\text{Ca}^*$, produced through inverse kinematical reaction $^{28}\text{Si}+^{12}\text{C}$ at same excitation energy [83]) had indicated a possible signature of enhancement in fragment yield (for relatively heavier fragments; $6 \leq Z \leq 8$) over those predicted by the statistical model.

As the fragment emission study of the reactions (a) $^{16}\text{O}$ (117, 125, 145 and 160 MeV) + $^{12}\text{C}$ indicated the possibility of dinuclear orbiting, the energy and angular distribution of α-particles have been studied to measure the deformation of the produced composite, $^{28}\text{Si}^*$. The measured energy spectra have been compared with the same predicted by the standard statistical model calculations. It has been found that the experimental α-particle energy spectra are properly explained by CASCADE only when an appreciable amount of deformation is introduced by optimizing the ‘deformability’ parameters. The extracted quadrupole deformation parameters are found to be large (larger than the corresponding RLDM values) at all beam energies. It is also observed that the deformation is found to increase with increasing the spin of the excited com-
posite. The observed enhancement of deformation in the present study may be another indication of orbiting in $^{16}\text{O} + ^{12}\text{C}$. However, the understanding does not seem to be so simple and straightforward when one compares the above with the results of CASCADE calculation with ‘frozen’ deformation, which has also been shown to be almost equally effective in explaining the data. In this case, the effective ‘frozen’ deformation turned out to be smaller than that obtained using the optimised parameters (though it is still higher than the corresponding RLDM value). So, the uncertainties about the magnitudes of the actual compound nucleus deformations notwithstanding, it can, only qualitatively, be said that equilibrium orbiting, which is similar to particle evaporation in time scale, could also be one of the contributing factors for the observed deformation. However, the present models are too simplistic to predict the actual deformation of the compound nucleus; more realistic event-by-event Monte Carlo calculations, taking into account the initial deformation, spin distribution of the compound nucleus and their subsequent evolutions, should be performed to have a proper understanding of the compound nucleus deformation. In addition, new experimental inputs (like measurement of deformation from GDR studies [120]) are needed for more comprehensive understanding of the process.

The DI component of the fragment ($3 \leq Z \leq 5$) energy distribution in all the three reactions (b) has been studied in details. It has been shown that the DI fragment angular distribution falls off much faster than $1/\sin \theta_{c.m.}$ distribution. The time scale of the DI process has been estimated from these DI angular distributions. It has been observed that for all these reactions, the time scale, which is related to net nucleon transfer, decreases as the fragment charge increases (closer to the projectile charge). It has also been observed that the average $Q$-values for the DI fragments decrease with the increase of emission angle and saturate at higher angles, signifying a saturation in energy damping process beyond these angles. Assuming a compact exit channel configuration (estimated from the extracted FF part of the spectra), the angular momentum dissipation factor, $f$, for the DI process has been extracted. For all the three
reactions, the experimental values of $f$ have been found to be in fair agreement with
the corresponding sticking limit predictions.

A large high vacuum reaction chamber has been designed, fabricated and installed
in SSC beam line-I. This Segmented, Horizontal Axis, Reaction Chamber (SHARC)
will cater to needs of different types of experiments using the facilities being developed
under superconducting cyclotron utilization project, VECC. SHARC is a cylindrical,
three segment, stainless steel (SS 304L) chamber of length 2.2m, diameter 1m and
total volume including the pipes to connect the pumps is $\sim 1800$ litres and wall thick-
ness $\sim 10$mm. The front (beam-entry) end is hemispherical in shape of radius 500mm
and the rear end is elliptical dish (2:1) shaped. All three segments are mounted on
separate support structures which rest on external rails such that each segment can
move independently on the rails by automatic gear-motor control mechanism having
built-in limit switch locking facility with manual override option. Two pairs of rails
are provided within the chamber for mounting and placement of the target ladder sys-
tem and the user designed detector assemblies at any position within the chamber. A
generalized detector mounting table (made of Aluminum alloy 6061-T6) with preci-
sion alignment mechanism on manually movable stands with locking arrangement on
rails is also provided as default arrangement. All over this table, there are inverted
‘T’-shaped channels which may be used for detector mounting in a general experi-
ment. There is provision to adjust the height of the table as per requirement of the
experimental setup. The table can be easily removed from the chamber if the rails are
sufficient to mount the detector system. To achieve optimum vacuum performance,
all inside surfaces were given smooth granular finish and were finally electro-polished
with bright finish. A target assembly is there inside the chamber; linear and rotational
motion is fully controlled very precisely with the help of two vacuum compatible step-
per motor and programmable logic controller. The whole assembly is mounted on one
pair of internal rails and may be placed at any position within the chamber to optimize
the flight path. The target assembly includes a ladder that can hold six targets at a time
in a column. Two glass windows are kept to visually inspect the positions of the target
and the detector inside and also to see the beam spot at the target position (on alumina, during optimisation of beam transport) using a camera outside the chamber. SHARC has been provided with 24 ports (each of diameter 25 cm) on different locations of the body of chamber to cater to various experimental requirements, like, the connections of gas flow system, electrical signals from the detectors, detectors bias inputs, cooling pipes (if required) etc. Flanges with standard LEMO connectors as well as indigenously designed and fabricated flanges with Flat Ribbon Connector (FRC) connectors has been used as electrical feed-through to take the detector signals. The design of the pumping system has been done by considering the possible degassing load due detector systems. Two sets of pumping systems, connected in parallel, have been used to achieve the ultimate vacuum. Each set consists one turbo pump (speed 1000 l/s ) and one cryo pump (pumping speed 2500 l/s) each backed by scroll pump ( peak pumping speed 37m$^3$/h). Whole pumping system is auto controlled by PLC. The chamber is successfully commissioned in the SSC beam line and the nominal vacuum of $\sim 5 \times 10^{-7}$ mbar has been achieved in 8 hours in empty condition.