Chapter 7

Summary and outlook

“If it disagrees with experiment, it is wrong”..............Richard P. Feynman.

This thesis contains a theoretical study of the collective transverse in-plane flow as well as its disappearance, thermalization, and other related phenomena like density, temperature, participant-spectator matter, and time zone for hot and dense nuclear matter in heavy-ion collisions at intermediate energies. The quantum molecular dynamics (QMD) model was used to calculate the time evolution of the phase-space of nucleons. The calculated phase-space was, then, analyzed to study the various phenomena.

The detail of different theoretical models was discussed in Chap. 2. We discussed, in particular, the quantum molecular dynamics model used for present study.

In Chap. 3, we have studied the mass dependence of the disappearance of flow in a large number of colliding nuclei with masses between 47 and 476 where experimental balance energy is available in most of the cases. We have shown a weak dependence of flow as well as its disappearance on different cross sections for heavier colliding nuclei. Our calculations indicate that balance energy indeed exists for $^{197}$Au+$^{197}$Au reaction. A power law mass dependence also exists for heavier nuclei with power factor close to 0.5. We also compared our calculations with experimental data which gave us a possibility to predict the balance energy for $^{238}$U+$^{238}$U to be 37-39 MeV/nucleon. Our calculations with a stiff equation of state are in good agreement with experimental data. We could also reproduce the slope of the power law ($\propto A^\alpha$) over a wide range of masses. Our calculations suggested a cross section of 35-40 mb in this incident energy domain. We have also shown that the collective flow due to mean field is attractive whereas it is repulsive.
for collision part. The balancing of these two parts results in the disappearance of flow.

In Chap. 4, our aim was to understand the impact and role of momentum dependent interactions in the transverse flow and in its disappearance obtained in central collisions involving masses between 24 and 394 (i.e., between $^{12}$C+$^{12}$C and $^{197}$Au+$^{197}$Au). We observed that the momentum dependent interactions play different role in lighter colliding nuclei compared to heavier colliding nuclei. In lighter nuclei, the contribution of mean field towards flow is much small compared to heavier nuclei where binary nucleon-nucleon collisions dominate the scene. The inclusion of momentum dependent interactions also explains the energy of vanishing flow in $^{12}$C+$^{12}$C which otherwise was not possible with static hard equation of state.

In Chap. 5, we presented the mass dependence of various quantities (such as the average and maximum central density, temperature, collision dynamics, and participant-spectator matter, as well as the time zone for hot and dense nuclear matter) at the energy of vanishing flow (balance energy). This study was conducted using a hard equation of state along with a nucleon-nucleon cross section of 40 mb strength. This combination is reported to explain the experimentally extracted balance energy for a large number of cases. Our calculations present several interesting facts. The reaction saturation time is smaller for the lighter nuclei compared to the heavy ones. The maximal values of the density, temperature, and collision rate are also shifted accordingly. In all the cases (i.e., in the average and maximum central density, temperature, participant and spectator matter, etc.), a power law dependence can be seen. The only quantity where power factor \(\tau\) is significant (with \(\tau \geq 0.2\)) is the temperature reached in the central zone. Other quantities are nearly mass independent. The mass independent nature of the participant matter makes it a good alternative indicator for determining the balance energy that can be measured experimentally, and our predictions can be verified.

In Chap. 6, we studied the participant matter and collision dynamics as a function of the mass of the system for different model parameters at central as well as peripheral colliding geometries. We observed a remarkable mass independent as well as model ingredients independent nature of the participant matter at the energy of vanishing flow which makes it a very strong alternative candidate to study the balance energy. We have
also shown that the participant matter can also act as an indicator to study the degree of thermalization reached in heavy-ion reaction. We have also presented the study of equilibrium (i.e., thermalization) in heavy-ion collisions at intermediate energies for which we simulated the reactions of $^{40}\text{Ca}+^{40}\text{Ca}$, $^{131}\text{Xe}+^{118}\text{Sn}$, and $^{197}\text{Au}+^{197}\text{Au}$ at different colliding geometry as well as at different incident energies.

Summarizing, we have attempted to understand the mass dependence and model ingredients dependence in various phenomena of heavy-ion collision such as collective transverse in-plane flow and its disappearance, density, temperature, participant-spectator matter etc. We studied the mass dependence in disappearance of flow for very wide range of masses between 24 and 476. A clear agreement with experimental data allowed us to predict the balance energy, for the first time, in $^{238}\text{U}+^{238}\text{U}$. The study of participant matter indicates a mass independent and model ingredients independent nature of participant matter making it as an alternate candidate to measure the balance energy.

There seems a need for the systematic study of various phenomena in heavy-ion collisions at peripheral colliding geometries. Moreover, various other types of flow such as differential, radial, elliptic flow etc. can also be studied. It would be of further interest to extend the flow analysis to isospin effects also.