Current status and future scopes of heavy-ion reactions around the Fermi energy domain

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The study of nuclear reactions is a diverse field, allowing to address a wide range of nuclear properties and other areas of science and technology. In low energy heavy ion collisions (below 20 MeV/nucleon), the reaction mechanism is dominated by mean field as collisions are Pauli blocked and the main reaction channels are fission, particle evaporation, deep elastic collision etc. On the other extreme, high energy reaction (from 2 GeV/nucleon to few TeV/nucleon) focuses on the creation and observation of a new state of matter namely quark-gluon-plasma where the mechanism is dominated by collision and the effect of mean field is less important. But in between these two i.e. at intermediate energy domain (from 20 MeV/nucleon to 2 GeV/nucleon) there is a competition between mean field and nucleon-nucleon collision and the most dominant reaction channel is nuclear multifragmentation [1].

In order to study the multifragmentation phenomena in the Fermi energy regime, experimental methodology has been developed over the last four decades at NSCL (at MSU, USA), Superconducting Cyclotron at Texas A&M university (USA), GANIL (Caen, France), Heavy-ion Synchrotron SIS accelerator at GSI (Germany), Superconducting Cyclotron at INFN (Catania, Italy), Riken (Japan) etc. In India, beam from K=500 superconducting cyclotron for performing experiments of nuclear multifragmentation is now available at Variable Energy Cyclotron Centre, Kolkata. Different theoretical models have been developed for throwing light on the intermediate energy heavy-ion reaction and for explaining the relevant experimental data. The theoretical models can be classified into two main categories: (i) dynamical models (where the detailed time evolution of the projectile and target nucleons are studied) and (ii) statistical models (based on the assumption of thermodynamic equilibrium at the freeze-out condition). Based on the statistical (more specifically canonical thermodynamical model (CTM) [1–3]) and dynamical (BUU@VECC-McGill model [1, 4, 5]) model studies, this presentation will focus on the present status and future opportunities of following three aspects of heavy-ion reactions around the Fermi energy domain-(i) mass distribution and production of intermediate mass fragment (IMF) and neutron rich nucleus in nuclear multifragmentation (ii) study of nuclear liquid-gas phase transition and (iii) search for nuclear symmetry energy at sub-saturation densities.

The evolution of fission (or evaporation) to multifragmentation at higher excitation can be understood by the fragment mass distribution and IMF production. Mass distribution of different fragments and IMF multiplicity for $^{112}Sn +^{112} Sn$ reaction obtained from canonical thermodynamical model with semi-microscopic cluster functional [3], are shown in Fig. 1. At temperature $T = 3$ MeV (lower excitation of compound nuclear system) fission is the dominating channel and IMF (atomic number of the fragment is in between 3 to 20) multiplicity is negligible. But at $T = 5$ MeV (moderate excitation), fission channel disappears and multifragmentation is the dominant process with a large number of

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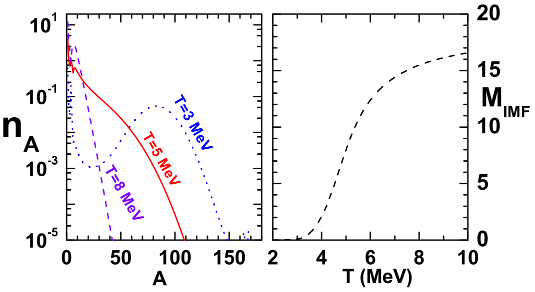

FIG. 1: Left panel: Mass distribution $^{112}Sn + ^{112}Sn$ studied at T=3 MeV (dotted line), 5 MeV (solid line) and 8 MeV (dashed line). Right panel: Variation of IMF multiplicity with temperature.

IMF being formed. With further increase of temperature from 5 MeV to 8 MeV (very high excitation) the system mainly breaks into a larger number of smaller mass fragments. Significant amount of very neutron rich isotopes are produced in multifragmentation reaction around the Fermi energy domain.

Another important area in the study of intermediate energy heavy ion collisions is the phenomenon of nuclear liquid gas phase transition [6, 7]. Phase transition is usually characterized by the specific behavior of the state variables like pressure, density, energy etc. In heavy ion collisions there is no direct way of accessing these state variables and hence unambiguous detection of phase transition is not possible. In a recent work [8] based on CTM calculation, first order derivative of total fragment multiplicity with respect to temperature is proposed as a new signature of nuclear liquid gas phase transition which is easily accessible in laboratory experiments. The peak in the multiplicity derivative exhibit completely identical behavior as that of the variation of the specific heat at constant volume which is an established signature of first order phase transition. This theoretically proposed new signature of nuclear liquid-gas phase transition is re-confirmed theoretically from different statistical as well as dynamical models by various nuclear reaction groups around the world. Very recently, peak in multiplicity derivative and its coincidence with specific heat is experimentally verified at the Texas cyclotron facility [9].

One of the most exciting challenges in modern nuclear physics and astrophysics is to understand the behavior of nuclear matter under extreme conditions [10]. Intermediate energy heavy-ion reactions provide a unique opportunity to enrich our knowledge about the nuclear equation of state at sub-saturation densities. In particular, the isoscaling [11–13] and isospin transport [14] in heavy-ion reactions around the Fermi energy domain is directly correlated to the density dependence of the nuclear symmetry energy. The sensitivity [12, 13, 15] of these isospin dependent observables to the density dependence of the symmetry energy will be discussed.

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