Signatures of nuclear liquid gas phase transition from transport model calculations for intermediate energy heavy ion collisions

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There is an enormous amount of experimental and theoretical work on liquid-gas phase transition in heavy ion collisions at intermediate energy [1]. The standard methods of theoretical studies on nuclear liquid-gas phase transition assume that because of two body collisions nucleons equilibrate and then multifragmentation occurs either at constant volume (most prevalent assumption) or at constant pressure. But the acceptability of either of these assumptions is a debatable issue. This work focuses on whether results of transport model calculations at intermediate energy can point to signatures of phase transition as it bypasses all such assumptions.

Boltzmann-Uehling-Uhlenbeck (BUU) transport model [2] is very successful in studying intermediate energy heavy ion collisions. In BUU model each nucleon is represented by N_{test} test particles. The standard BUU model describes the properties of the average of all events. But to get the multiplicity distribution in nuclear multifragmentation from complete dynamical model calculation one needs an event by event description, not just the average of all events. Later it has been extended to include fluctuations which made it suitable for event-by-event simulation where at each time step all test particles are allowed to collide with one another [3]. But it required a huge computing time and the application of the model was limited to collisions of low mass nuclei (mass∼30). Hence, a simplified yet accurate method is developed [4] which can reduce the computation time of two body collisions by a factor of $1/N^2_{test}$. Therefore this model can easily simulate the nuclear reactions of fairly large nuclei (this is important because the finite number effects often hide the bulk effects).

To study phase transition, central collision reactions between projectile of mass $A_p = 120$ and target of mass $A_t = 120$ are simulated at different projectile energies (E_p). Fig. 1 shows the variation of multiplicity (n_a) against mass number (a) at four different E_p's. For each energy, 1000 events are taken. The results of averages for groups of five consecutive mass numbers are shown. At low beam energy

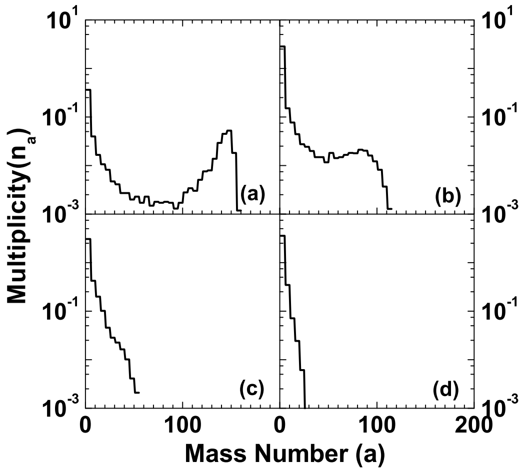

FIG. 1: Mass distribution for $A_p = 120$ on $A_t = 120$ reaction at beam energies (a)50 MeV/nucleon, (b) 75 MeV/nucleon (c) 100 MeV/nucleon and (d) 150 MeV/nucleon. Only central collisions are considered here but even at $E_p = 50$ MeV/nucleon, nucleons in the peripheral region passes through and largest fragment remaining is less than the sum of the masses of the two nuclei.

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(50 MeV/nucleon) the multiplicity first falls with mass number a, reaches a minimum, then rises again, reaches a maximum before disappearing. As the beam energy increases the height of the second maximum decreases. At E_p =75 MeV/nucleon the second maximum is still there but barely visible. At higher energies the multiplicity is monotonically decreasing, the slope becoming steeper as the beam energy increases. The disappearance of the second maximum indicates phase transition, which was obtained earlier [5] from canonical thermodynamical model (CTM) calculation.

Fig. 2 compares transport model results with

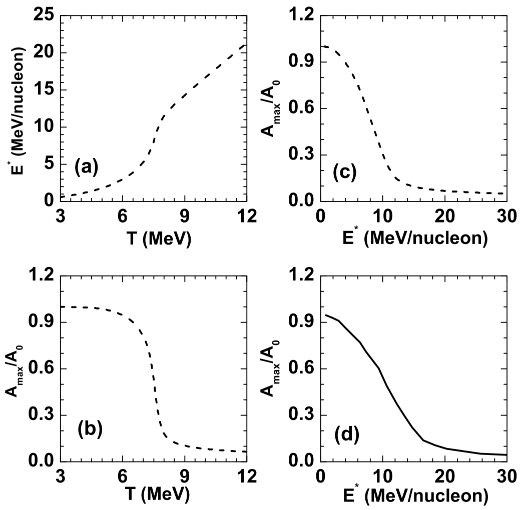

FIG. 2: Top left curve (a) is a CTM calculation for E^* vs.T for $A_0 = 192$. Bottom left curve (b) is also a CTM curve showing the variation of the size of largest cluster with temperature. Top right (c) is also with CTM but A_{max}/A_0 is plotted against excitation energy per nucleon instead of temperature. The change of liquid to gas is necessarily slower, the range of energy for the change is dictated by latent heat. Bottom right (d) is the calculation from transport model.

CTM results. In BUU, temperature (T) can not be calculated directly. With proper consideration of pre-equilibrium emission (20% of total nucleons, as observed in experiments) the excitation (E^*) of the fragmenting system at different E_p can be determined from the transport model [6]. In CTM, T gives an average excitation E^* of the multifragmenting system. The top left diagram is E^* vs. T in CTM for 192 particles (A_0=192=80% of 240, remaining 20% is pre-equilibrium emission). This approximates usual E^* vs T for first order phase transition. There is a boiling point temperature T which remains constant as energy increases. Between 6 MeV and 7.5 MeV temperatures, E^* rises quickly. In the example here because we deal with a very finite system, the slope dE^*/dT is not infinite but high. Let us now consider lower left diagram again drawn with CTM. Here A_{max} is the average value of the largest cluster. A high value of A_{max}/A_0 means liquid phase and low values means gas phase. A_{max}/A_0 drops sharply between T =6 MeV and 7.5 MeV. In the bottom left diagram, one sees more dramatically that in a short temperature interval liquid has transformed into gas. The only input in the BUU model is the beam energy. The common dynamical variable in both BUU model and CTM is E^*. The top right corner of Fig. 2 is the plot of A_{max}/A_0 as a function of E^* with CTM. The transformation from liquid to gas is more gradual, essentially spanning the energy range across which, liquid transforms totally into gas. Even for a large system, where the transformation of liquid to gas as a function of temperature is very abrupt, the transformation as a function of energy per particle will be quite smooth. The bottom right in Fig. 2 is from the BUU calculation.

The similarity of BUU results with that of CTM is close enough to make us conclude that the transport model calculation gives evidence of liquid-gas phase transition.

References

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