Nuclear phase transition: new observables representing the signatures

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Heavy ion collisions at intermediate energies exhibit a phenomenon, known as nuclear multifragmentation, which is very similar to liquid-gas phase transition, where an excited nuclear system produces a few small fragments along with a liquid like heavy residue or may explodes into several small gaseous fragments depending upon the excitation energy. Different signatures of such transition of a highly excited nuclear system have been predicted from the theoretical models as well as have been observed in the experiments.

Usually people study the thermodynamic variables like pressure, energy, specific heat etc. to describe the features of phase transition. For first order phase transition, as in this case, variation of excitation energy with temperature gives a region where at a particular temperature excitation energy jumps discontinuously and specific heat diverges at transition point. These are very well known signatures of 1st-order phase transition. For nuclear multifragmentation such signatures of 1st-order phase transition are theoretically well established but there are some difficulties in experimental measurement. Thermodynamic observables as energy, specific heat etc. are not easily accessible in experiment. So the direct experimental signature of phase transition is not very accurate.

Therefore to overcome such problems we have tried to find new observables, which are easily accessible in experiment and can give the signatures of phase transition. In a recent work [1] we have established that the total multiplicity i.e., the total number of fragments produced in nuclear fragmentation can give the signature of phase transition. Variation of temperature derivative of the total multiplicity, like specific heat, gives a prominent peak at transition temperature. In this present work we introduce other two observables, average size of the largest cluster $\langle A_{max} \rangle$ and a_2, which are accessible in experiments and show the signals of phase transition. The average size of the largest fragment obtained from fragmentation of nuclei is a very important observable in fragmentation study as it distinguishes between nuclear liquid and gaseous

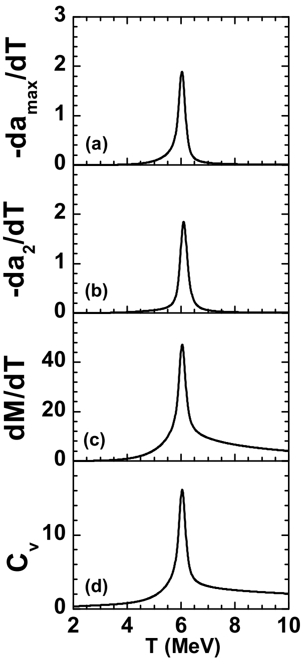

FIG. 1: Variation of the derivative of (a) average size of the largest cluster($\langle Z_{max} \rangle$), (b) a_2, (c) Multiplicity (M), (d) C_v with respect to temperature (T) for a fragmenting system of mass $A_0 = 200$ [3].

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phases. Thus it acts as the order parameter of nuclear phase transition. Furthermore, bimodal nature of the probability distribution of the largest cluster size at a certain temperature is taken as signature of phase coexistence and the transition temperature is identified where one get two peaks of equal height. There are experimental signatures in favor of bimodality but both theoretical and experimental identification of transition point is doubtful as the bimodal probability distribution loose its prominence due to finiteness of the system size. The normalized parameter a_2 is defined as,

$$a_2 = \frac{\langle A_{max} \rangle - \langle A_{max-1} \rangle}{\langle A_{max} \rangle + \langle A_{max-1} \rangle},$$

where A_{max-1} is the average size of the second largest cluster. Beside $\langle A_{max} \rangle$, a_2 also used as order parameter of phase transition.

Using Canonical Thermodynamical Model (CTM) [2] of nuclear multi-fragmentation we have studied $\langle A_{max} \rangle$ and a_2 and the derivative of them with respect to temperature for different temperatures [Fig.1]. It has been observed that the temperature derivative of those observables give sharp peak, similar to the multiplicity, and C_v at transition point. The transition point obtained from all the four cases coincide at the same temperature. Thus one can get successfully the signals of first-order phase transition from these two observables [3]. The study has been done considering an ideal one-component system consisting of single type nucleons without coulomb interaction. The work including coulomb interaction for real nuclear system is in progress.

References

[1] S. Mallik, G. Chaudhuri, P. Das, and S. Das Gupta, Phys. Rev. C 95, 061601(R) (2017).

[2] C.B. Das, S. Das Gupta, W.G. Lynch, A.Z. Mekjian, M.B. Tsang, Phys. Rep. **406**, 1 (2005).

[3] P. Das, S. Mallik, G. Chaudhuri, Phys. Lett. B **783**, 364 (2018).