Isospin effect on liquid-gas phase transition for finite nuclei

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I. INTRODUCTION

One of the most important motivation of nuclear physics community is to probe the liquid-gas coexistence region in the phase diagram of nuclear matter [1, 2]. Intermediate energy heavy-ion reaction (projectile energy ranging from 20 MeV/nucleon to 2 GeV/nucleon) is an unique method to study nuclear phase transition for finite nuclei in laboratories [3]. However, in heavy-ion reactions, there is no direct way of accessing the thermodynamic state variables, hence unambiguous detection of phase transition becomes difficult. The difficulty of accessing these state variables experimentally was motivated to look for more direct signatures of phase transition. First order derivative of total fragment multiplicity with respect to temperature (multiplicity derivative) has been proposed as a new signature [4] of nuclear phase transition which is easily accessible in laboratory experiments. The peak in the multiplicity derivative exhibits completely identical behavior [4, 5] as that of the specific heat at constant volume which is an established signature of first order phase transition. The properties of nuclear liquid gas phase transition are correlated to the nuclear equation of state (EoS) [6] at sub-saturation densities and finite temperatures. The aim of this work is to study the effect of EoS and isospin asymmetry of the fragmenting system on the nuclear phase transition signatures (multiplicity derivative and specific heat) in the framework of Canonical thermodynamical model (CTM).

II. THEORETICAL FORMALISM

In CTM, [7] it is assumed that statistical equilibrium is attained at freeze-out stage and population of different channels of disintegration is solely decided by statistical weights in the available phase space. This model has been recently upgraded with semi-microscopic cluster functional [8] where the bulk part of the binding and excitation has been determined from the meta-modelling of the EoS [9]. In order to study the effect of EoS on phase transition, semi-microscopic cluster functional of the CTM is updated with three commonly used nuclear EoS-(i) Sly5 (ii) NL3 and (iii) SGII [9] and fragmentation of a nuclear system of mass number A_0=72 and atomic number Z_0=30 is simulated. Nuclear phase transition from heavy-ion reactions at intermediate energies can be explained as the competition between the surface energy and excitation energy. The surface tension effect tries to accumulate more nucleons together (i.e. prefers

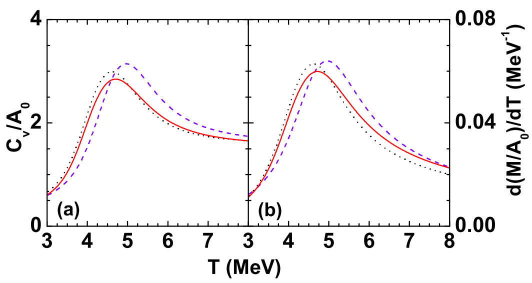

FIG. 1: Variation of (a) specific heat and (b) multiplicity derivative with temperature studied from CTM with semi-microscopic cluster functional based on Sly5 (solid lines), SGII (dotted lines) and NL3 (dashed lines) EoS for the fragmenting system having A_0=72 and Z_0=30.

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liquid phase) on the other side excitation of the nucleus tries to break it in to free nucleons and small composites (i.e. prefers gas phase). Here surface energy of a fragment is identical, but the excitation energy of different fragments at a given temperature obtained from SGII (NL3) EoS are higher (lower) compared to that of Sly5 EoS. Hence, the peak of the specific heat per particle at constant volume (C_v/A_0) as well as multiplicity derivative normalised by fragmenting system mass number $\frac{d(M/A_0)}{dT}$ (which represents the temperature at which nuclear phase transition occurs) obtained from CTM calculation with SGII (NL3) EoS shifted towards lower (higher) temperature compared to that of Sly5 EoS.

To study the effect of isospin asymmetry on nuclear phase transition for finite nuclei, CTM calculation with semi-microscopic cluster functional (with Sly5 EoS only) is performed for two sets of disintegrating system- (i) fixed Z_0=30 but three different A_0=72, 66 and 60 (which are expected to be formed in central collision of ^{48}Ca+^{48}Ca, ^{40}Ca+^{48}Ca and ^{40}Ca+^{40}Ca reactions respectively with 25% pre-equilibrium emission [10]) (shown in Fig. 2) and (ii) fixed Z_0=75 but three different A_0=186, 177 and 168 (which represent ^{124}Sn+^{124}Sn, ^{112}Sn+^{124}Sn and ^{112}Sn+^{112}Sn reactions respectively with the same initial condition). For both cases (displayed in Fig. 3), peak of C_v/A_0 and $\frac{d(M/A_0)}{dT}$ almost coincides for all three systems which indicates the dependence of phase transition temperature (T_p) on isospin asymmetry is very less.

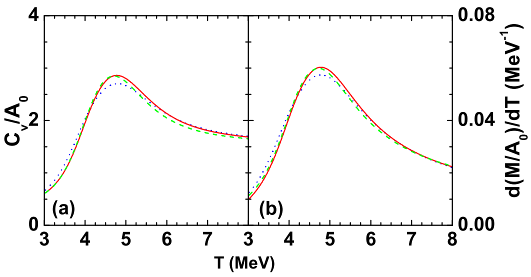

FIG. 2: Variation of (a) specific heat and (b) multiplicity derivative studied from CTM with semi-microscopic cluster functional based on Sly5 EoS for the fragmenting system having same Z_0=30 but different A_0=60 (dotted lines), 66 (dashed lines) and 72 (solid lines).

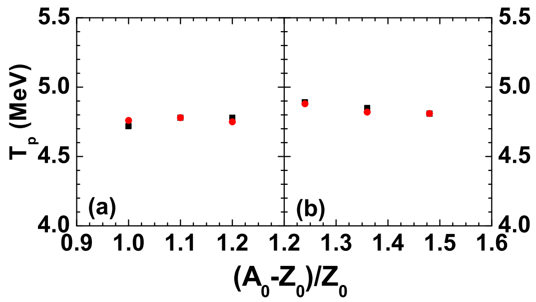

FIG. 3: Isospin dependence of the phase transition temperature obtained from peak of specific heat per particle (squares) and multiplicity derivative (circles) for fragmenting systems having atomic number (a) 30 and (b) 75.

III. CONCLUSION

Nuclear phase transition temperate is sensitive to the EoS but it's dependence on isospin asymmetry of the fragmenting system is almost negligible for finite nuclei.

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