Effect of hyperons on nuclear phase transition

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Phase transition of nuclear system in heavy ion-collisions at intermediate energy has been studied well for many years and it has also been extended to strange nuclear matter. Recently, using the Canonical Thermodynamical Model(CTM), detailed work [1] on multiplicity distribution of fragments produced from fragmentation of hypernuclear system shows the existence of phase transition or phase coexistence in strange system with Λ-hyperons. In present work we want to continue the investigation on phase transition with respect to some other thermodynamic observables like free energy, specific heat etc. in order to be confirmed about the nature of the transition.

According to CTM [2], a system consisting of Z_0 protons, A_0 baryons and H_0 hyperons has expanded to a volume (freeze-out volume V_f) greater than normal nuclear volume (V_0) where the system is assumed to be in thermodynamic equilibrium and its temperature is T and the system breaks into several composites such that total charge, mass and strangeness are conserved. We apply statistical mechanics to calculate different observables of interest since we have assumed that the statistical equilibrium is reached. From this model the total partition function of the system is given by,

$$Q_{A_0,Z_0,H_0} = \sum_{Channel} \prod_{i,j,k} \frac{(\omega_{ijk})^{n_{ijk}}}{n_{ijk}!} \quad (1)$$

This partition function is calculated from the recursion relation,

$$Q_{A_0,Z_0,H_0} = \frac{1}{A_0} . \sum_{ijk} i.\omega_{ijk}.Q_{A_0-i,Z_0-j,H_0-k} \quad (2)$$

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where ω_{ijk} is the intrinsic partition function of a composite of mass i, charge j and hyperon k and n_{ijk} is the no. of such composites in a particular partition [2,3]. Now once we get the partition function we can calculate required observables like Helmholtz free energy(F), entropy(S), specific heat(C_p), pressure(P) from the following well known thermodynamical relations,

$$F = -T \ln Q_{A_0,Z_0,H_0} \quad (3)$$

$$S = -\left(\frac{\partial F}{\partial T}\right)_V \quad (4)$$

$$C_V = T\left(\frac{\partial S}{\partial T}\right)_V = -T\left(\frac{\partial^2 F}{\partial T^2}\right)_V \quad (5)$$

$$P = T\frac{\partial \ln Q_{A_0,Z_0,H_0}}{\partial V} \quad (6)$$

In our present study, we have considered two fragmenting systems both of them have charge $Z_0 = 50$, mass $A_0 = 128$ but one is normal nuclear system with no hyperons in it, $H_0 = 0$ and other is hyper nuclear system having $H_0 = 8$ hyperons. The coulomb effect has not been considered to get better signature of phase transition in a finite system. In Fig 1.a the Helmohltz free energy curves are continuous in nature and there is not much difference between the two plots. Fig 1.b shows the variation of entropy i.e., 1st order derivative of free energy with temperature which shows a discontinuous behavior at certain temperature range around 6MeV. Discontinuity is more prominent for strange system. Fig 1.c gives the temperature variation of specific heat. It exhibits a strong peak near T=6MeV and the peak is stronger for the system with hyperons. Discontinuity in first derivative of free

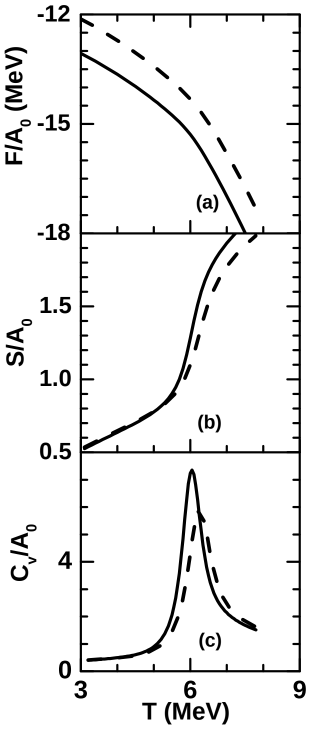

FIG. 1: Variation of Helmholtz's free energy per nucleon(upper), entropy per nucleon (middle) and specific heat per nucleon (bottom) with temperature for two fragmenting systems having the same $A_0 = 128$, $Z_0 = 50$ but different $H_0 = 8$(solid lines) and $H_0 = 0$(dashed lines).

energy and peak in second derivative are the signature of first order phase transition and this signature is more pronounced in case of strange matter. Another important point is that the position of the peak on the X-axis i.e., transition temperature is different for different system. Transition temperature of the strange system is lower than that of the normal system. This is because strange system carries additional excitation energy compared to normal system since hyperons are heavier than normal nucleons. So it disintegrates at a

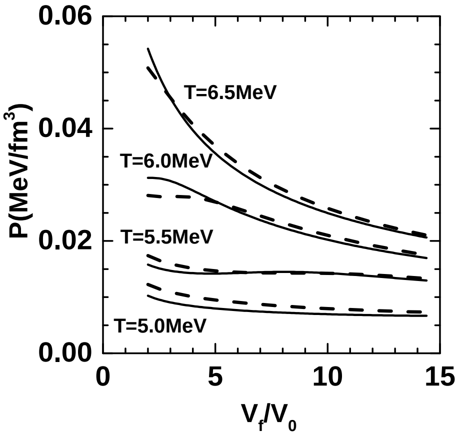

FIG. 2: Variation of pressure with volume for two fragmenting systems having the same $A_0 = 128$, $Z_0 = 50$ but different $H_0 = 8$ (solid lines) and $H_0 = 0$ (dashed lines) at four different temperatures T =5.0, 5.5, 6.0 and 6.5 MeV.

lower temperature than normal one.

Next in Fig 2. we have shown the isotherms at four different temperatures in pressure-volume plane which are very important in the study related to 1st order phase transition. At T=6.5MeV, both normal and strange system are completely in gaseous phase. But at lower temperatures , there is a constant liquid-gas co-existance region. Here also we observe that strange system breaks at a smaller volume than normal one.

From the study we come into the conclusion that the hypernuclear matter shows 1st order phase transition. The signature of the phase transition is more profound for the strange system and also the transition temperature is smaller than normal one.

References

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