Hypernuclear liquid gas phase transition

P. Das, G. Chaudhuri,* and S. Mallik
Theoretical Nuclear Physics Group, Variable Energy Cyclotron Centre,
1/AF Bidhan Nagar, Kolkata 700 064, INDIA

The physics of hypernuclei is an important area of study in the regime of high energy heavy ion collisions. As seen in experiments, hyperons (usually Λ) originating from the hot participant region have a extended rapidity distribution and some of these can be absorbed in the much colder spectator parts. Subsequently these spectators may break producing cold and possibly exotic hypernuclei. For theoretical description of this fragmentation process Canonical Thermodynamical model (CTM) [1] has already been extended to three component systems [2] i.e, inclusion of hyperons (Λ) in addition to the protons and the neutrons.

In recent days, liquid-gas phase transition or phase coexistence of normal nuclei [3] is also a hot topic in the nuclear physics community. Whether this phase-coexistence will still persist in the presence of hyper-fragments (strange fragments) is the object of investigation in this paper.

In CTM, it is assumed that a system with A_0 baryons, Z_0 protons and H_0 hyperons at temperature T, has expanded to a higher than normal volume where the partitioning into different composites can be calculated according to the rules of equilibrium statistical mechanics. According to this model, the average number of composites with a baryons, z protons and h hyperons can be calculated from,

$$< n_{a,z,h} >= \frac{\omega_{a,z,h} Q_{A_0-a,Z_0-z,H_0-h}}{Q_{A_0,Z_0,H_0}}$$

where, $\omega_{a,z,h}$ is the partition function of one composite with a baryons z protons and h hyperons and Q_{A_0,Z_0,H_0} is the total partition function which can be calculated from the recursion relation,

$$Q_{A_0,Z_0,H_0} = \frac{1}{A_0} \sum_{a,z,h} a\omega_{a,z,h} Q_{A_0-a,Z_0-z,H_0-h}$$

The details of the model can be found in Ref. [2, 4].

In the present calculation, the fragmenting hypernuclei is assumed to have mass number $A_0 = 128$, charge $Z_0 = 50$ and total strangeness $H_0 = 8$. Fig. 1 shows the distribution of hyperfragments ($\langle n_h \rangle = \sum_{a,z} \langle n_{a,z,h} \rangle$) at different temperatures (excitation energies). At lowest temperature 3 MeV, the distribution resembles 'U' shape. This nature is very much similar to what one obtains in the case of mass distribution of normal fragments at low temperature. This 'U' shape of mass distri-

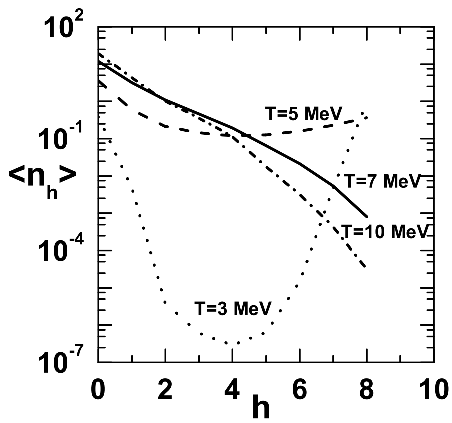

FIG. 1: Distribution of hyperfragments produced from the fragmentation of $A_0 = 128$, $Z_0 = 50$, $H_0 = 8$ at $T = 3$ MeV (dotted line), 5 MeV (dashed line), 7 MeV (solid line) and 10 MeV (dash-dotted line).

*Electronic address: gargi@vecc.gov.in

bution for normal fragments and the lowering down of the height of the maxima on the higher mass side as temperature is increased is usually linked to first-order phase transition or phase coexsistence [1]. Similar feature also emerges here for the case of hyperfragments. With similar reasoning as in the case of normal (non-strange) fragments, we can associate this phenomenon in hyperfragments with phase coexistence or liquid-gas phase transition. There is existence of hyperfragments with small strangeness content as well as large strangeness content at the same time. As we increase the temperature ($T = 5$ MeV), the so called 'U' shape gradually flattens and finally at higher temperatures ($T = 7$ and 10 MeV), it changes to monotonically decreasing pattern as is seen from the figure. This can be inferred as disappearing of liquid phase as the temperature is increased.

In order to further analyze the distribution

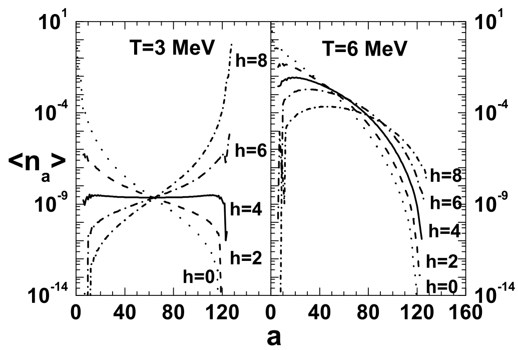

FIG. 2: Mass distribution h=0, 2, 4, 6 and 8 hyperfragments produced from the fragmentation of $A_0 = 128$, $Z_0 = 50$, $H_0 = 8$ at $T = 3$ MeV (left panel) and 6 MeV (right panel).

of strangeness content in different fragments of varying mass, we have calculated their mass distribution with different h values separately. Fig. 2 displays this mass distribution ($\langle n_{a,h} \rangle = \sum_z \langle n_{a,z,h} \rangle$) at two different temperatures 3 and 6 MeV. At $T = 3$ MeV, for $h = 0$ that is for the normal fragments with no strangeness, the nature of the curve is monotonically decreasing which shows that the production cross-section of heavier fragments with no strangeness content is extremely less. This can be interpreted by the fact that the hyperons tend to get attached to the heavier fragments at lower temperature and hence most of the heavier fragments are strange. This is confirmed by the other plots in the same figure which shows the mass distribution for fragments with different strangeness content, i.e, $h = 2, 4, 6$ or 8. More is the mass number of a fragment, greater is the probability of more hyperons getting attached to it. On the contrary, the strangeness content of lower mass fragments is comparatively less. The multiplicity of fragments with $h = 0$ or $h = 2$ is much more for lower values of a. For small strangeness content, the multiplicity decreases as one increases a. So at a single temperature $T = 3$ MeV, the non-strange fragments or fragments with lower strangeness remains in the gas phase where as the fragments with higher strangeness are in the liquid phase. The right side of this figure shows the plot for a higher temperature $T = 6$ MeV. As the temperature increases, fragments with higher mass decrease for obvious reasons. Lighter mass fragments are predominant at higher temperatures and they contain little or no strangeness. So, at $T = 6$ MeV, non-strange as well as all strange fragments remains in the gas phase.

Hence, by studying hyperon and mass distributions we can conclude that the hypernuclei also exhibits liquid gas phase transition in a certain temperature interval. It will be interesting to study other thermodynamic variables like average size of largest cluster, specific heat etc. for the case of fragmentation of hypernuclei. We plan to work on this.

References

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