Multiplicity Derivative: A new signature of phase transition in Nuclear Multifragmentation

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Establishing evidence for phase transition in nuclear matter from data obtained from intermediate energy heavy ion collision has attracted much attention in the last twenty years. Phase transitions occur in large systems and signatures of phase transition can be masked by finite sizes. In nuclear physics the Coulomb interaction prevents formation of very large systems in the laboratory. In addition to limiting the size of nuclei, Coulomb effects also suppress signatures of phase transition. If finite size and Coulomb effects totally mask the signature of phase transition then no definite conclusions can be reached from the data. It is known that the corruptive effects of Coulomb interaction is so strong that bimodality which is a signature of first order phase transition gets destroyed. We suggest that the situation is not that ambiguous. We will show in this work that there is an observable which points to vestiges of first order phase transition and we will use the canonical thermodynamic model (CTM) [1] to establish our claim.

Measurement of M, the total multiplicity, for central collision between comparable mass heavy ions can provide a signature for first-order phase transition. The derivative of M with respect to E^*/A where E^* is the excitation energy in the centre of mass and A the total mass of the dissociating system is expected to go through a maximum as a function of E^*. Theoretical modeling shows that this is the energy where the specific heat C_v maximizes which typically happens at the first-order phase transition. The measurement of M is feasible in most of the experiments.

In all statistical models of nuclear multifragmentation, the basic assumption is that an excited system of Z protons and N neutrons expands to a volume greater than normal nuclear volume and disintegrate into fragments. It is also assumed that the system attains thermal and chemical equilibrium at freeze-out characterized by a temperature T and a volume V_f. There are different versions of the statistical models depending on the en-

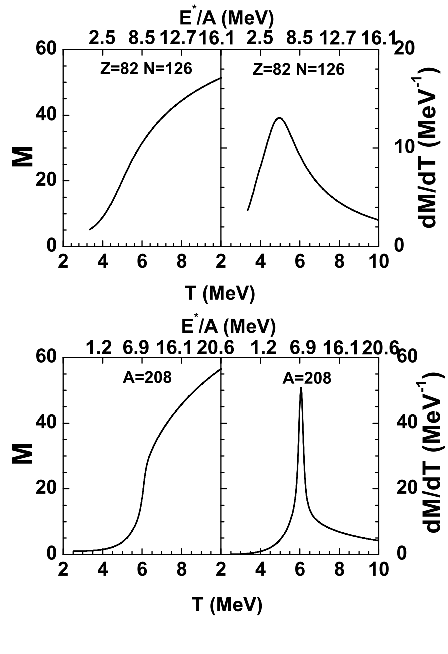

FIG. 1: Variation of multiplicity M (left panels) and dM/dT (right panels) with temperature (bottom x-axes) and excitation per nucleon (top x-axes)from CTM calculation.

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semble used and most of them have quite successfully reproduced the data from heavy-ion collisions. Results from CTM and the statistical multifragmentation model(SMM) by the Copenhagen group[2] have been found to be very close [3]. Here we use CTM. In central collisions of nearly equal mass ions one can measure with 4π detectors the total multiplicity $M = \sum M_a$. Here a denotes the mass numbers of composites. In CTM the derivative of M with T as a function of T is seen to have a maximum[4]. Fig.1 shows the total multiplicity for fragmenting system having proton number (Z)=82 and neutron number (N)=126 and and its derivative dM/dT. Results for both real nuclei (upper panel) and the one for one kind of particles with no coulomb(lower panel) have been displayed in order to emphasize the effects of Coulomb interaction. The rise and the peak are much sharper in absence of Coulomb interaction clearly indicating the role of the long range interaction. It can be shown that as the system size decreases , the features become less sharp[4]. Of course experiments do not give T directly but a plot against E^*/A will also show a nearly coincident maximum.

The peak in dM/dT coincides with the maximum of specific heat at constant volume C_v [4] as a function of temperature(see Fig 2). The peak in C_v is a signature of first order phase transition. In dM/dT, we have the peak coinciding with that of C_v and hence we are proposing it as a new method for testing the occurrence of first order phase transition in heavy ion collisions. Even where bimodality develops, it may be easier to locate the position of the maximum in the derivative of M since the bimodal region is very narrow.

It is well known that composites from CTM are excited and hence will undergo sequential decay [5] which will change the total multiplicity. We have examined this and found that this will not alter our conclusions. In fact, sequential decay makes the peak in dM/dT sharper.

Here we have used measurable dM/dE as evidence for first order phase transition should a maximum be seen. The answer is unambiguous: it is either yes or no. Most past investigations have suffered from ambiguity. One model that predicted first order phase transition was the lattice gas model [6] but the property of M was not investigated. It will be interesting to pursue that in a future work.

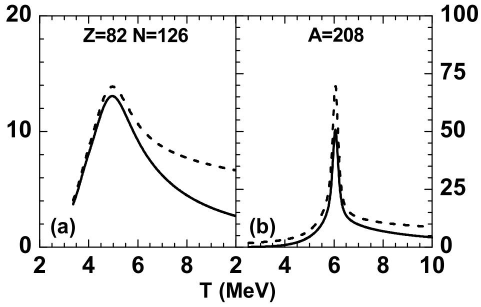

FIG. 2: Variation of dM/dT (solid lines) and C_v (dashed lines) with temperature from CTM for fragmenting systems having Z=82 and N=126 (left panel) and for hypothetical system of one kind of particle with no coulomb interaction of mass number A=208 (right panel). To draw dM/dT and C_v in the same scale, C_v is normalised by a factor of 1/50.

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