Study of multiplicity derivative as a new signature of nuclear liquid gas phase transition from lattice gas model

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The study of liquid-gas phase transition is an important area of research in the regime of fragmentation of nuclei in heavy ion collisions [1, 2]. Different signatures of this transition have been studied extensively both theoretically and experimentally. The variation of excitation energy and specific heat with temperature are two well studied signatures to detect the first order phase transition. The specific heat at constant volume peaks at the transition temperature if there is a liquid gas transition. The difficulty of accessing this signature experimentally motivated us to look for more direct signatures of phase transition and first order derivative of multiplicity has been recently proposed as a new signature [3] of liquid gas phase transition in nuclear multifragmentation.

In Ref. [3], we have observed the coincidence of the peak of multiplicity derivative and specific heat from Canonical Thermodynamical Model (CTM) [4]. Very recently W. Lin et. al. also observed the same signature from Statistical Multifragmentation model (SMM) [5] The basic physics assumptions of CTM and SMM are same; for some other observables the results of CTM and SMM were compared and they were found to be very close [6].

In this work, we examine features of multiplicity derivative from lattice gas model which is widely different from standard thermodynamic models like CTM. Let $A = N + Z$ be the number of nucleons in the system that dissociates. In lattice gas model [7], we consider D^3 cubic boxes where each cubic box has volume $(1.0/0.16)fm^3$. D^3 is larger than A. Here $D^3/A = V_f/V_0$ where V_0 is the normal volume of a nucleus with A nucleons and V_f is the freeze-out volume where partitioning of nucleons into clusters is computed. For nuclear forces one adopts nearest neighbor interactions in the lattice gas model. For this work, we will consider the fragmentation of a system having Z=82 and N=126 and the simulation is done at

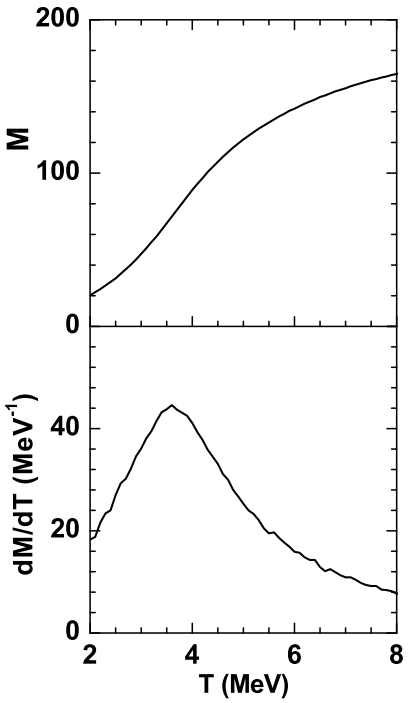

FIG. 1: Variation of M (upper panel) and $\frac{dM}{dT}$ (lower panel) with T obtained from lattice gas model for fragmenting system having Z=82 and N=126

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D=8. Following normal practice, we use neutron-proton interactions v_{np}=-5.33 MeV and set $v_{nn} = v_{pp}$=0.0. Coulomb interaction between protons is included. Each cube can contain 1 or 0 nucleon. There is a very large number of configurations that are possible (a configuration designates which cubes are occupied by neutrons, which by protons and which are empty; we sometimes call a configuration an event). Each configuration has an energy. If a temperature is specified, the occupation probability of each configuration is proportional to its energy: P$\propto$exp(-E/T). This is achieved by Monte-Carlo sampling using Metropolis algorithm.

Calculation of clusters need further work. Once an event is chosen we ascribe to each nucleon a momentum. Momentum of each nucleon is picked by Monte-Carlo sampling of a Maxwell-Boltzmann distribution for the prescribed temperature T. Two neighboring nucleons are part of the same cluster if $\vec{P}_r^2/2\mu + \epsilon < 0$ where ϵ is v_{np} or v_{nn} or v_{pp}. Here $\vec{P}_r$ is the relative momentum of the two nucleons and μ is the reduced mass. If nucleon i is bound with nucleon j and j with k then i, j, k are part of the same cluster. At each temperature we calculate 50,000 events to obtain average energy $< E >$ and average multiplicity n_a (where a is the mass number of the cluster) of all clusters. A cluster with 1 nucleon is a monomer, one with 2 nucleons is a dimer and so on. The total multiplicity is $M = \sum n_a$ and $\sum a n_a = A$ where $A = N + Z$ is the mass number of the dissociating system.

Variation of total multiplicity and its derivative with temperature obtained from lattice gas model calculation is shown in Fig. 1. Comparison of dM/dT and $c_v = d < E > /dT$ are shown in Fig 2. It is clear that, c_v goes through a maximum at some temperature which is a hallmark of first order phase transition and this occurs at the same temperature where dM/dT maximises. This is very similar to CTM results of Ref. [3, 8] corroborating the evidence that the appearance of a maximum in dM/dT is indicative of a first order phase transition [9].

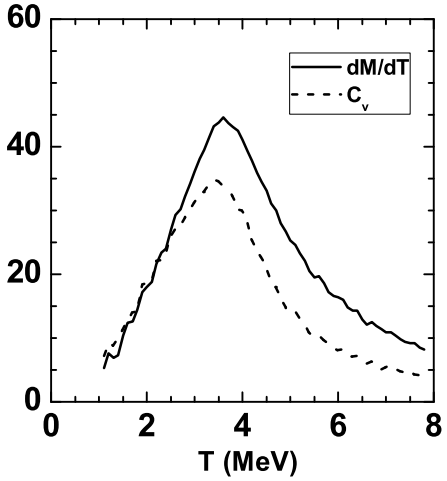

FIG. 2: Variation of dM/dT (solid line) and C_v (dashed line) with temperature from lattice gas model for fragmenting system having Z=82 and N=126. To draw dM/dT and C_v in the same scale, C_v is normalised by a factor of 1/10; dM/dT is unit of MeV^{-1}.

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