Cluster Emission and Phase Transition Behavior in the Nuclear Disassembly

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Phase transitions and critical phenomena are extensively studied. In the intermediate energy domain, several experimental observables or mechanisms have been suggested to characterize the nuclear liquid-gas phase transition, e.g., latent heat and caloric curves [1], critical exponent analyses [2] Fisher droplet scaling [3], negative heat capacities [4], spinodal decomposition [5], etc.

Theoretically, several models have been developed to treat such a phase transition in the nuclear disassembly, e.g. percolation model, lattice gas model (LGM), statistical multifragmentation model and molecular dynamics model. (See recent review articles of Richert and Wagner [6] and Das Gupta et al. [7]).

In this work, we are interested in LGM and classical molecular dynamics (CMD) model of Pan and Das Gupta [8]. The former is a simple short-range interaction model, but it can be successfully applied to nuclear systems with isospin symmetry and asymmetry. The LGM calculation is carried assuming that the system is at a 'freeze-out' density (ρ_f) with thermal equilibrium at temperature *T*. Previous calculations with LGM showed that there exists a phase transition for the finite nuclear systems. This resulted from studying the effective power law parameter τ of the cluster mass distribution or charge distribution, their second moments S_2 and the specific heat. More recently, we proposed two novel criteria, namely multiplicity information entropy *H* and *A* nuclear Zipf's law to diagnose the onset of liquid-gas phase transition in the framework of the LGM and CMD model [9].

In this work, we show that the emission rate of clusters is a useful tool to diagnose the nuclear liquid-gas phase transition.

Fig. 1 displays the slopes of average multiplicity of the emitted neutrons S_{Nn} (a), protons S_{Np} (b), charged particles S_{Ncp} (c), and intermediate mass fragments S_{Nimf} (d) and the slopes of the mean mass of the largest fragment S_{Amax} (e) as a function of temperature in different 'freeze-out' density (ρ_f) in the framework of LGM. Sharp changes are observed at nearly the same temperature for each fixed 'freeze-out' density. At such a transition point, the multiplicities of emitted clusters increase rapidly. After that, the emission rate slows down, and the decrease in the largest fragment size reaches a minimum for such a finite system. Physically, the largest fragment is simply related to the order parameter ρ_l - ρ_g (the difference of density in nuclear 'liquid' and 'gas' phases). In infinite matter, the infinite cluster exists only on the `liquid' side of the critical point. In finite matter, the largest cluster is present on both sides of the phase transition point. In this calculation, a minimum for the slope of A_{max} with temperature may correspond to a sudden disappearance of the infinite cluster ('bulk liquid') near the phase transition temperature.

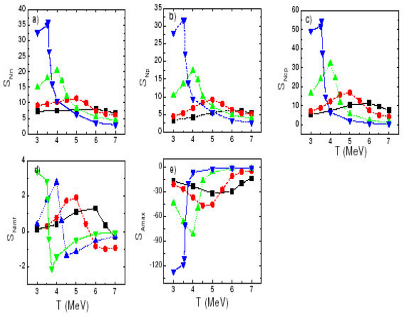

Figure 1: The slopes of average multiplicity of the emitted neutrons SNn (a), protons SNp (b), charged particles SNcp (c) and intermediate mass fragment SNimf (d), the slopes of the mean mass of the largest fragment SAmax (e) as a function of temperature in different 'freeze-out' density (ρf) in the framework of LGM. The inverted triangles, triangles, circles and squares represent ρf = 0.097, 0.18, 0.38 and 0.60, respectively.

This idea is supported by surveying the other phase transition observables, such as the effective power law parameter τ from the

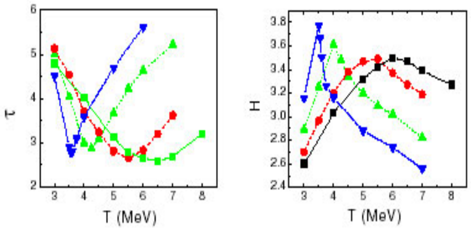

Figure 2: The effective power law parameter $\boldsymbol{\tau}$ of cluster mass distribution (left) and the information entropy ***H*** (right) as a function of temperature in different `freeze-out' densities (ρ_f) in the framework of LGM. The symbols are the same as in Fig. 1.

mass or charge distribution of fragments and the information entropy H of the event multiplicity distribution [9]. The minimum of τ and the maximum of H characterize the liquid-gas phase transition temperatures (see Fig. 2).

We obtain similar results with CMD as those of LGM even though the phase transition temperature is shifted due to the repulsive Coulomb interaction, which makes the phase transition temperature lower. The conclusion that the emission rates of multiplicities can be taken as a signature of liquid-gas phase transition does not change. For details, see [10].

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