Excitation Energy Evolution of the Density in Nuclear Mmultifragmentation

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In multifragmentation reactions, the thermal pressure due to sufficiently large excitation energy drives the nuclear system, to a low density region, beyond which it ceases to exist in a mono-nucleus state and disassembles into many fragments. This density is often referred to as the " break-up " or the "freeze-out" density. Theoretically, the freeze out density in all statistical models is defined as that density in the space-time evolution of the fragmenting system where the nuclear interaction among the generated fragments become frozen, and the fragments thereafter mediate with each other only through their Coulomb interactions. The freeze-out density is generally taken to be independent of the excitation energy and differs appreciably from model to model. Experimentally, two different methods have been adopted so far to study the evolution of density as a function of excitation energy. In one study [1], the density has been determined from Coulomb barriers required to fit the intermediate mass fragments kinetic energy spectra. In another [2], it has been determined from the analysis of apparent level density parameters required to fit the measured caloric curves. Both studies show that the density of the multifragmenting system decreases with increasing excitation energy. However, the two sets of results are not in agreement with each other at higher excitation energies ($E^* > 5$ MeV/nucleon). It is observed that densities derived from Coulomb barrier systematics are comparatively lower than those derived from the level density parameters at higher excitation energies.

In this work, we determine the density by requiring a fit to the excitation energy dependence of the isoscaling parameter and the excitation energy dependence of the temperature (i.e. the caloric curve) simultaneously. We make use of the expression for the isoscaling parameter α as a function of excitation

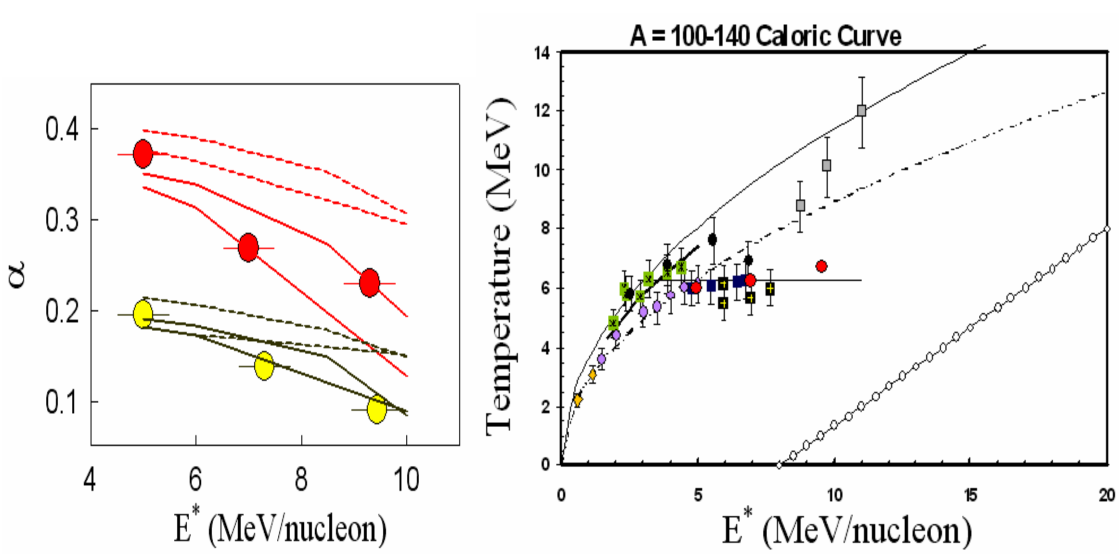

Figure 1. Experimental isoscaling parameter α and temperature as a function of excitation energy. The data points (other than the red symbols) in the right figure is taken from Ref. [2].

energy and the expanding Fermi gas relation, assuming that the temperatures in both relations are correlated. Fig. 1 (left) shows the isoscaling parameter α as a function of the excitation energy for the A ~ 100 nuclei. Fig. 1 (right) shows the temperature versus the excitation energy plot (solid red symbols) obtained from the present study that is consistent with the excitation energy dependence of the α parameter.

Fig. 2 shows the excitation energy dependence of the density from the present measurements (symbols with error bars). The results of Viola et al.[1], and Natowitz et al.[2], are also shown for comparison. The solid curve in the figure corresponds to the breakup density calculated from the statistical multifragmentation model by Bondorf et al., [3]. The present measurements show a decrease in the density with increasing excitation energy and are in good agreement with those determined from the apparent level density parameter by Natowitz et al. The closer agreement between the present measurements and the calculated density seem to indicate that the density obtained from the present measurements and those obtained from the apparent level density parameter might be characteristic of much earlier stage of the expanding system i.e., before the freeze-out, and when the fragment yield or charge distribution is determined and the density is still evolving with excitation energy. The density obtained from the Coulomb barrier systematic might be characteristic of a later stage i.e., the freeze-out stage, where the density has ceased to evolve and the fragment kinetic energy is determined. This indicates that two characteristics volume and density might be important in understanding the multifragmentation process.

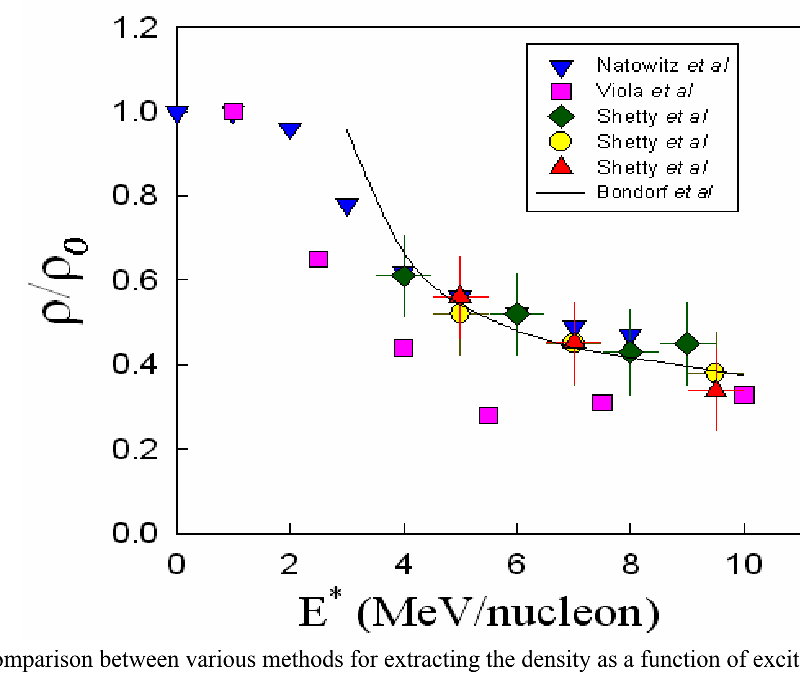

Figure 2. Comparison between various methods for extracting the density as a function of excitation energy.

[1] V. Viola *et al.*, Phys. Rev. Lett. **93**, 132701 (2004).

[2] J.B. Natowitz *et al.*, Phys. Rev. C **66**, 031601(R) (2002).

[3] J. Bondorf *et al.*, Nucl. Phys. **A444**, 460 (1985)