Thermal expansion, effective mass and nuclear caloric curve

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The experimentally observed "plateau" in the nuclear "caloric curve" (temperature versus excitation energy) has long been seen as a signature of liquid-gas phase transition, similar to that in water. Recently [1], it has been argued that the plateau in nuclear caloric curve is a consequence of a combined effect of decreasing density due to thermal expansion and the evolution of in-medium nucleon effective mass, rather than an indication of liquid-gas phase coexistence. A pseudo plateau, in variance with the one expected from the simple Fermi gas relation, is to be expected in the nuclear caloric curve with or without a multifragmentation-like phase transition. Furthermore, the inclusion of the surface expansion degree of freedom (surface diffuseness) along with the self- similar expansion degree of freedom, leads to a plateau [2] even flatter than the one obtained using just the self-similar expansion degree of freedom. The caloric curve for finite mononuclear system therefore exhibits not simply a pseudo plateau but a real one.

The above schematic model for describing the caloric curve is based on the relaxation of density profile of the mononucleus that results in maximum entropy under a local density approximation for the level density parameter. The plateau in the caloric curve from this model is however established at a rather modest excitation energy (about 2 MeV/nucleon), well before where one usually considers the liquid-gas phase transition to occur. The evolution of effective mass with density and excitation in the above prescription is included in a schematic fashion as they are currently unknown.

In this report, we show that a plateau in the caloric curve can also be obtained under various different assumptions regarding the role of effective mass as a function of excitation energy, and the collective expansion energy. The caloric curve thereby obtained exhibits a plateau at somewhat higher excitation energy compared to those obtained by Sobotka *et al.* [2], and in better agreement with the experimental data. Fig. 1 shows a comparison between the caloric curve obtained from the present study and the experimental data. The inverted triangle symbols corresponds to the experimentally measured caloric curve data for the mass range of A = 100 – 140, compiled by Natowitz *et al.* [3], from various measurements. The data from all different measurements are shown here collectively and no distinction is made between them. The black dashed curve is the simple Fermi gas relation, with the inverse level density parameter K_o = 10. The Fermi gas relation explains the data at low excitation quite well, but fails at higher excitation energies. The brown dashed curve corresponds to the expanding Fermi gas relation,

$$T^2 = K_o(\rho/\rho_o)^{2/3}E^* \qquad (1)$$

The density ρ/ρ_o as a function of excitation energy E* in the above equation was assumed to be similar to that adopted by Bondorf *et al* [4]. This form of dependence is also similar to that obtained by Natowitz *et al* [5], for the break-up densities obtained from the analysis of the apparent level density parameters. This equation does not include the momentum and the frequency dependent factors in the effective mass ratio that are important at lower excitation energies. As a result of which, this relation does a poor job of reproducing the data at excitation energies below 4 – 5 MeV/nucleon. At higher excitation energies, the effective mass ratio reduces to one, and hence shows good agreement with the

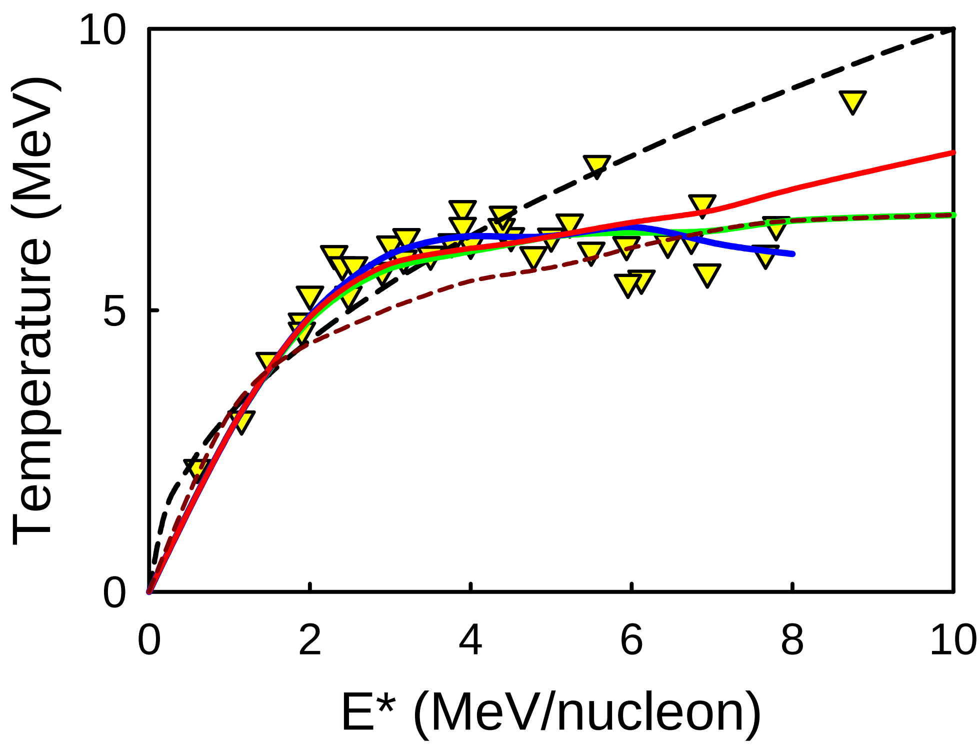

Figure 1. Temperature as a function of excitation energy for A = 100 - 140. The curves are from the present study. The data are taken from Ref. [3].

data. Accounting for the excitation energy dependence of the effective mass (as shown by the green curve in fig. 2) as discussed in Refs. [6] and [7] in the above equation as one obtains the relation,

$$T^2 = K_o(m^*/m)(\rho/\rho_o)^{2/3}E^* \quad (2)$$

The above equation results in a significant flattening of the caloric curve (shown by green curve in Fig. 1). Note the effective mass ratio m*/m, in Fig. 2 reduces to one at higher excitation energy. The above expression for the temperature versus excitation energy with the effective mass dependence assumes a collective expansion energy of the form $(1 – (\rho/\rho_o)^{2/3})$. If the expansion energy is assumed to be a simple upside down bell shaped form, as suggested by Friedman [8], $\varepsilon_b(1 – \rho/\rho_o)^2$, where ε_b = 8 MeV, one obtains a dependence given by,

$$T^2 = K_o(m^*/m)[E^*-8(1-\rho/\rho_o)^2] \quad (3)$$

This is shown by the red curve in Fig. 1. One observes that both the red and the green curve with different assumption of the collective expansion energy, but the same effective mass dependence, leads to similar results at excitation energies below 6 MeV/nucleon, except for a small deviation at higher excitation energies. Both calculations show plateau at excitation energies in agreement with the data. A much stronger, but unphysical, effective mass dependence (shown by blue curve in Fig. 2) along with simple Fermi gas relation leads to significant flattening of the caloric curve as shown by the blue curve in Fig. 1.

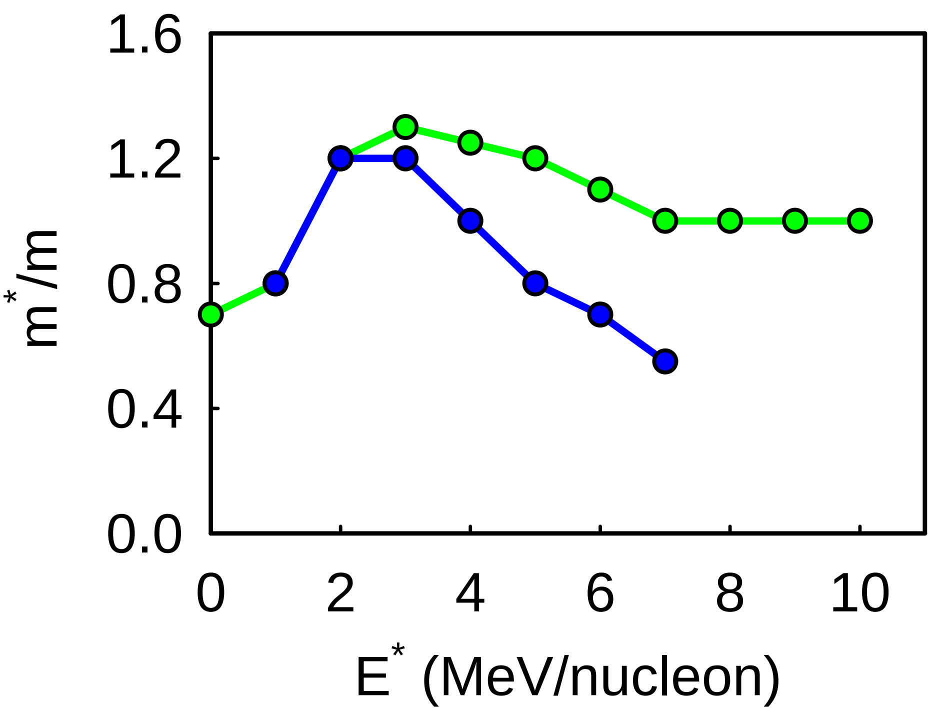

Figure 2. Effective mass ratio as a function of excitation energy.

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