Signatures of the liquid-gas phase transition in multifragmentation

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The identification of a possible liquid-gas phase transition in nuclear matter is presently a subject of great interest. From the experimental point of view the equilibrated systems formed in heavy ion collisions follow an *unknown* path in the excitation energy (E)-freeze-out volume (V) plane, not necessarily along the order parameter of the system, which prevents any deduction concerning the existence of a liquid gas phase transition from the simple analysis of the nuclear caloric curve [1]. It was recently shown that a constant microcanonical pressure path is a good order parameter even for small systems with long range forces like the nuclear ones [2]. It is believed that the experimentally formed equilibrated nuclear systems have a freeze-out volume fluctuating from one event to another, somewhat similar to a "constant λ" ensemble [with the partition function given by $Z(E,\lambda) = \int \mathrm{d}V W(E,V)\exp(-\lambda V)$, where $W(E,V)$ is the microcanonical density of states and λ is the Lagrange multiplier corresponding to the volume observable] [1]. It was recently argued that, if one has to deal with fluctuating volume systems, their spinodal regions are (likely to be) signaled by negative values of the heat capacity curves irrespective to the path followed by the system in the (E,V) plane [1, 3]. Therefore rigorous microcanonical formulas are required in order to evaluate these quantities. Such formulas can be simply obtained starting from the observation that the microcanonical density of states corresponding to a given excitation energy may be written as:

$$W(E) = \sum\!\!\!\!\!\!\int \mathrm{d}\mathcal{E}\,\mathcal{F}(C)\,(E-\mathcal{E})^{\frac{3}{2}(N-n)-1}, \qquad (1)$$

where $\sum\!\!\!\!\!\int \mathrm{d}\mathcal{E}() \equiv \sum_{N=1}^{A}\prod_{i=1}^{N}\left(\sum_{A_i,Z_i}\int \mathrm{d}\mathbf{r}_i\int \mathrm{d}\epsilon_i\right)() \equiv \sum_C W(C)$ and $\mathcal{F}(C)$ is a function depending on the specific system's configuration $C : \{A_i, Z_i, \epsilon_i, \mathbf{r}_i,\ i = 1,\ldots,N\}$ and n is an integer number depending on the imposed restrictions (i.e. E const.: $n=0$; E and $\mathbf{P}$ const.: $n=1$; E, $\mathbf{P}$ and $\mathbf{L}$ const.: $n=2$). The microcanonical temperature and heat capacity formula are respectively given by $T^{-1} = \partial S/\partial E$ and $C^{-1} = -T^2\left(\partial^2 S/\partial E^2\right)$, with $S = \ln W(E)$. *If* the limits of the above integral are not depending on E, then the derivative versus E can be performed *inside* the integral. The resulting expressions are:

$$\begin{aligned}
T^{-1} &= \left\langle \frac{\frac{3}{2}(N-n)-1}{K} \right\rangle, \\
C^{-1} &= 1 - T^2\left\langle \frac{\left[\frac{3}{2}(N-n)-1\right]\left[\frac{3}{2}(N-n)-2\right]}{K^2} \right\rangle, \\
\frac{\partial^2 S}{\partial E^2} &= \left\langle \frac{\left[\frac{3}{2}(N-n)-1\right]\left[\frac{3}{2}(N-n)-2\right]}{K^2} \right\rangle \\
&- \left\langle \frac{\frac{3}{2}(N-n)-1}{K} \right\rangle^2, \qquad (2)
\end{aligned}$$

with $\langle X \rangle = \sum_C W(C)X/W(E)$. Similar expressions can be obtained for the case when one has information about only a (small) number of fragments ($N_1 < N$) [3]. The applicability of the above formulas is restricted by the condition that the integration domains over $\mathcal{E}$ not to depend on E. This can be translated by the condition that the kinetic energy probability distribution not to intersect the $K=0$ axis at a non-negligible value [3]. An exemplification of the functioning of the obtained formulas [eqs. (2)] is given in Fig.1. There the results of these formulas for T, C and $\partial^2 S/\partial E^2$ are compared with evaluations of the same quantities by means of a different method dealing with probability distributions of isobaric canonical ensembles [2, 3]. The agreement is very good. The first order phase transition is signaled in the first two situations [the sources (50,23) with Coulomb interaction included and (200,82) without Coulomb interaction in a constant λ ensemble] through backbendings in the caloric curves, negative branches of the heat capacity curves or positive values of $\partial^2 S/\partial E^2$.

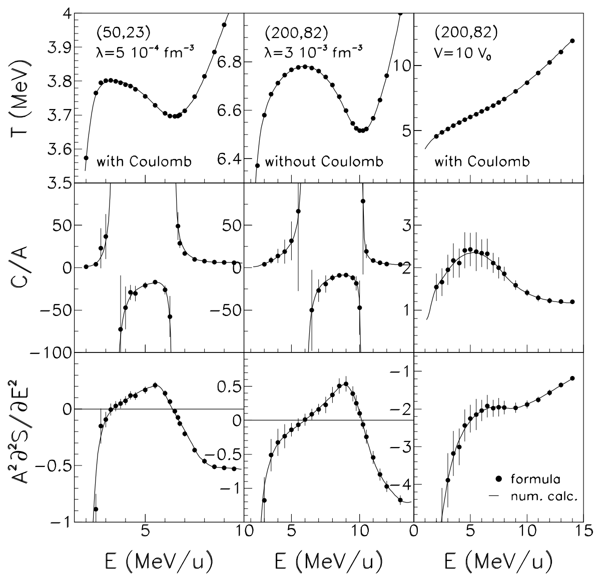

Figure 1: $T(E)$, $C(E)$ and $\partial^2 S/\partial E^2(E)$ curves calculated by means of eqs. (2) (black circles) in comparison with the corresponding results calculated from the probability distributions of a canonical ensembles at given volume constraints (constant λ; constant V).

References

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