A systematic study of the nuclear caloric curve(*)

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(ricevuto il 9 Giugno 1998; approvato il 28 Luglio 1998)

Summary. — Temperature-excitation energy correlation measurements on several systems at different incident energies are discussed in the framework of the investigation on possible liquid-gas phase transition in nuclear matter. Results are compared to the presently available experimental caloric curves. Moreover the isotope and the excited states temperatures, extracted from double ratios of isotope yields and population ratios of fragment unbound states, respectively, are compared. The differences on the temperatures deduced from the two methods cannot be accounted for by the sequential feeding corrections. Instead, they seem to be related to the space-time evolution of the fragmentation process.

PACS 25.70.Pq – Multifragment emission and correlations.
PACS 25.70.Mn – Projectile and target fragmentation.
PACS 01.30.Cc – Conference proceedings.

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1. – Introduction

Nucleus-nucleus collisions at intermediate and relativistic energies have been shown [1] to be an ideal tool to produce pieces of nuclear matter at extremely different thermodynamical conditions: both cold nuclear systems behaving as a Fermi liquid or hot fireball disintegrating in free nucleons and a few light clusters have been detected.

In order to analyse thermodynamical properties of nuclear systems we produce and select samples (microcanonical ensembles) at high excitation energies (i.e. approaching grand canonical ensembles): such samples can be produced either in head on collisions, where the excitation energy is determined by the incident beam energy, or in peripheral collisions at relativistic energies, where the spectator heating is controlled by the impact parameter.

The temperature-excitation energy correlation [2,3], quoted as “calorimetric measurement” along this paper, measured in the study of the projectile spectator fragmentation in $^{197}$Au+$^{197}$Au collisions at 600 $A$ MeV is reported in fig. 1. The similarity of this curve, referred to as the nuclear caloric curve in ref. [4], to first-order liquid-gas phase transitions in macroscopic systems, has initiated a widespread discussion which addresses both methodical aspects and questions of interpretation.

The role of the secondary sequential decay on temperature measurements has been widely discussed [5-8] in the framework of different models [9, 10]. Moreover recent results of calorimetric studies on Ar projectile at 95 $A$ MeV from INDRA [11] and Au on C at 1000 $A$ MeV from EOS [12] collaborations, compared to the one of ref. [4] (fig. 2), show a different behaviour that is interpreted as a continuous transition from the liquid to the gas phase. However, the observed discrepancies could be attributed to the system size [13] and to the dynamics of the multifragmentation process. In particular the collective radial flow, evidenced [14] in central collisions, has been shown to play an important role [15].

Therefore a systematic investigation of the calorimetric measurements dependence on the system size, incident energies and impact parameter is needed. In the present paper we discuss the results from the Xe, Au and U collisions on a variety of targets at incident energies between 50 and 1000 $A$ MeV done at the GSI (Darmstadt) [16], Ca+Sc and Nb+Nb at 40 and 15 $A$ MeV respectively at the LNS (Catania) and a few recent data from Kr+Nb and Ar+Sc collisions in the energy range between 35 and 120 $A$ MeV at the NSCL (MSU) [17], in comparison with the caloric curves of fig. 2.

2. – Experimental details

The Xe, Au and U projectile fragmentation at 400, 600 and 1000 $A$ MeV incident energies on Be, C, Al, Cu, In, Au and U targets was studied at the SIS accelerator at GSI with the ALADiN [18]-LAND [19] coupled devices [16].

The Au+Au system was further investigated at 50, 100, 150, 200 and 1000 $A$ MeV [22, 23]. We used seven telescopes around the target to allow isotope identification of fragments up to $Z = 6$ and three large-area Si-CsI hodoscopes with fine granularity that allow to reconstruct the yield of fragment unstable states from resonances in the correlation functions of their decay products. A schematic view of the experimental set-up is shown in fig. 3. With this set-up we selected: at 1000 $A$ MeV incident energy, the target spectator fragmentation (to reduce contributions from the fireball the hodoscopes were placed at backward angles with respect to the beam axis). At incident energies between 50 and 200 $A$ MeV, the interaction region in central collisions was studied. In the latter