Temperature and Fragment Spectra in Heavy Ion Collisions ◇

T. Gaitanos, H. H. Wolter, and C. Fuchs [a]
[a] Inst. für Theoretische Physik, Univ. Tübingen

One of the motivations in the study of heavy ion collisions is the understanding of the multifragmentation process in relation to phase transitions in the bulk material. The question is whether such thermodynamical concepts can usefully be applied in the dynamical, non–equilibrated situation of a heavy ion collision. A partial answer can be provided by analyzing the results of transport calculations in terms of thermodynamical quantities which has to be applied locally in view of the evolution of the system in space and time.

We obtain a local temperature, T_{loc}, from a fit of the momentum distribution by one or, in non–equilibrium, two Fermi distribution of finite temperature [1]. On the other hand we have generated fragment kinetic energy spectra in a phase space coalescence model [2]. These are analyzed in terms of a so–called blast model, as has also been done in experimental studies [3], which assumes a freeze–out configuration with a unique temperature and a radial flow pattern for all fragments . This yields a slope temperature, T_{slope}. We have applied these two methods to spectator and participant matter for Au on Au collisions at intermediate energies.

We showed previously that the spectator in such a reaction is well characterized by a local temperature of $T_{loc} \approx 5$ MeV [1]. It is also equilibrated, has no radial flow, and exhibits negative effective compressibility and thus instability. It is thus a good system to observe phase transitions. The slope temperatures from the fragment energy spectra, originating in the spectator, are given in Fig. 1. The fragment spectra with $A_f \geq 2$ exhibit a rather uniform slope temperature of about 17 MeV, which is in very good agreement with recent findings of the ALADIN collaboration [4]. The nucleon spectra, $A_f = 1$, on the other hand, exhibit two components with $T^{low}_{slope} \approx 7$ MeV and $T^{high}_{slope} \approx 20$ MeV. The lower component is due to the evaporation of the nucleons from the excited spectator matter and the temperature agrees about with $T_{loc} \approx 5$ MeV. The higher component is probably a contamination of nucleons originating from the participant matter (see below) which is never completely separated from the spectator.

The differences in the temperatures of the nucleons and the slope temperatures of the fragments most likely is due to contributions of the Fermi motion to the fragment spectra. This has been discussed by Bauer in the framework of the Goldhaber model [5]. These ingredients are included in the present treatment and show the applicability of these concepts in a microscopic framework.

A similar analysis has been performed for the participant matter (fireball) [6] in central Au on Au collisions and is shown in Fig. 2. Slope temperatures and the collective radial flow β are shown for different fragment masses. The radial flow agrees well with experimental analyses, considering that nucleons dominate the mass spectra. The slope temperature for nucleons, $A_f = 1$, agrees again with $T_{loc} \approx 30$ MeV at freeze–out, showing that the methods of temperature determination are consistent. For the heavier fragments, $A_f \geq 2$, on the other hand the slope temperature increases strongly with increasing mass. The average temperature is somewhat smaller relative to the data. However, the behavior of the fragment temperature is very different from that observed in the spectator. We thus conclude that the participant fragmentation is not well modelled by a freeze–out configuration of fixed temperature. Rather it seems that here fragments originate at different stages (densities and temperatures) of the collision. This will be investigated in more detail.

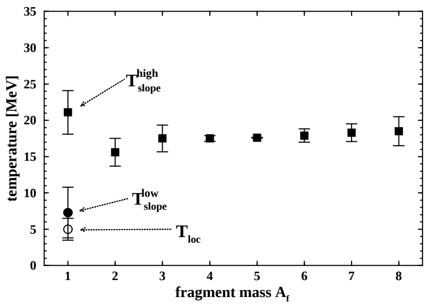

Fig. 1: Spectator temperatures as function of the fragment mass A_f for Au on Au at $E_{beam} = 600$ AMeV. (squares) slope temperatures, (circle) local temperature.

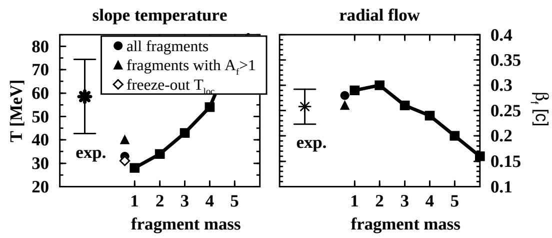

Fig. 2: Slope temperature (left) and radial flow (right) from blast model fits for different fragment masses separately and for all or for $A_f > 1$ fragments, together. A comparison to the freeze–out temperature T_{loc} and to experimental values [3] is shown ($Au + Au$ at 0.6 AGeV beam energy).

References

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