Unified Description of Freeze-Out Parameters in Relativistic Heavy Ion Collisions.

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It is shown that the chemical freeze-out parameters obtained at CERN/SPS, BNL/AGS and GSI/SIS energies all correspond to a unique value of 1 GeV per hadron in the local rest frame of the system, independent of the beam energy and of the target and beam particles.

We have found that a unified description of the hadronic abundances produced in heavy ion collisions at the CERN/SPS, the BNL/AGS and the GSI/SIS accelerators is possible. This description covers a range in beam energies from 200 A-GeV to below 1 A-GeV. As it turns out the same description can also be applied to the hadronic abundances in LEP and in \(p - p\) and \(\bar{p} - p\) collisions with slightly different treatment of strangeness sector which accounts for strangeness undersaturation. The result can be summarized in a surprisingly simple way: the hadronic composition of the final state is determined by an energy per particle being approximately 1 GeV per hadron in the rest frame of the produced system. This generalizes an observation made a long time ago by Hagedorn \(\[1\]\) for \(p - p\) collisions, namely, as one increases the beam energy, the available energy is used to produce more particles, but not to increase the temperature of the system. This led Hagedorn to the idea of a limiting temperature. For heavy ion collisions one has to take into account not only the temperature but also the finite baryon density of the system, which is described by the baryon chemical potential \(\mu_B\). This, as it was first indicated by P. Braun-Munzinger and J. Stachel \(\[2\]\), leads to a freeze-out curve in the \(T, \mu_B\) plane. In Fig. 1 the values of the freeze-out parameters are shown, as obtained by various groups (a recent summary can be found in \(\[3\]\)). The solid line corresponds to 1 GeV per hadron, the dashed line corresponds to 0.94 GeV per hadron. This energy corresponds to the chemical freeze-out stage, namely, before the hadrons decay into the stable hadrons.

It is well known that various effects (e.g. flow) severely distort the momentum spectra of the particles produced in heavy ion collisions. It has been repeatedly pointed out however that many of these effects cancel out for ratios of fully integrated particle multiplicities (see e.g. \(\[4\]\)). The analysis of particle ratios is therefore the best method to obtain reliable information on the chemical freeze-out parameters of the hadronic final state. Such an analysis, relying as much as possible on fully integrated particle multiplicities was carried out for BNL/AGS and for CERN/SPS data. In Fig. 1 the SPS points are indicated by open squares \(\[5,7\]\) while the AGS points are indicated by open circles \(\[5–7\]\).

Data using \(\text{Ni}\) and \(\text{Au}\) beams at energies between 0.8 and 1.9 A-GeV have become available recently from the GSI/SIS accelerator. These data have attracted considerable interest due to the surprisingly large number of \(K^-\) mesons being produced below threshold. A very detailed and extensive discussion of these results in the framework of thermal models has been presented in \(\[8–10\]\). The results for the freeze-out parameters for \(\text{Ni} - \text{Ni}\) at 1.9 A-GeV is shown as an open triangle in Fig. 1. The points with the lowest temperature correspond to \(\text{Au} - \text{Au}\) collisions at 0.8 and 1.0 A-GeV and \(\text{Ni} - \text{Ni}\) collisions at 1.0 and 1.8 A-GeV, and are also shown as open triangles.

A similar analysis has been performed in \(\[11\]\) for \(e^+e^-\) annihilation into hadrons at LEP. Since no baryons are involved here this corresponds to zero baryon chemical potential, \(\mu_B = 0\). An impressive fit has been obtained here since no less than 29 different hadronic abundances can be reproduced. It is our view that such a good agreement cannot simply be a coincidence. This analysis was subsequently extended \(\[12\]\) to \(p - p\) and \(\bar{p} - p\) reactions at CERN. In this case, one reproduces the Hagedorn temperature obtained many years ago.

In the underlying hadronic gas model all these points can be described by a single curve corresponding to a fixed energy per particle, \(\epsilon/n\), which has approximately the value of 1 GeV per particle in the hadronic gas. This value characterizes all the final states produced by beams having 1 A-GeV all the way up to 200 A-GeV. Thus, the only modification one needs to make to the concept of Hagedorn’s limiting temperature is that there exist a “limiting” - freeze-out energy per particle of 1 GeV at which hadrons are formed in a collision.

This observation leads to a considerable unification in the description of the hadronic final states produced in high energy collisions.

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FIG. 1. Freeze-out values obtained from hadronic abundances at CERN/SPS, BNL/AGS and GSI/SIS. Also indicated are the points obtained from observed hadronic abundances at LEP and in $p−p$ collisions at CERN. The smooth curves correspond to a fixed energy per hadron in the hadronic gas model.
