ENERGY DEPENDENCE OF THE INVERSE SLOPE PARAMETER IN HEAVY-ION COLLISIONS *

Y. Hama[a], F. Grassi[a], O. Socolowski Jr.[a], T. Kodama[b], M. Gaździcki[c] and M.I. Gorenstein[d]

[a]Instituto de Física/USP, C.P. 66318, 05389-970 São Paulo-SP, Brazil
[b]Instituto de Física/UFRJ, C.P. 68528, 21945-970 Rio de Janeiro-RJ, Brazil
[c]Institüt für Kernphysik, Universität Frankfurt, Frankfurt, Germany
[d]Bogolyubov Institute for Theoretical Physics, Kiev, Ukraine

(Received November 14, 2003)

We calculate, in a hydrodynamic approach, the m_T spectra of kaons in central Pb+Pb (Au+Au) collisions, as function of energy. The experimentally observed anomalous behavior of the inverse slope parameter T^* may be reproduced by a reasonable choice of the critical temperature $T_{\mathrm{c}} \sim 160$ MeV at $\mu = 0$ and an equally reasonable choice of energy-dependent freeze-out temperature T_{fo}, thus supporting the argument that these data are an additional signature of deconfinement transition.

PACS numbers: 12.38.Mh, 24.10.Nz, 25.75.–q, 25.75.Nq

1. Introduction

It has been predicted that several "anomalies" appear in the energy dependence of hadron producton in heavy-ion collisions and which would be signals of the deconfinement transition [1, 2]. One of such "anomalies", suggested a long time ago by Van Hove [3] in connection with multiparticle production in high-energy p–$\bar{p}$ interactions, would be a plateau-like structure in the energy-dependence of the inverse slope parameter of transverse-momentum distributions, often called effective temperature T^* [1]. Recent data on kaons produced in central Pb+Pb or Au+Au collisions show such a behavior as function of the collision energy [4]. As seen in Fig. 1, T^* for K^+ increases with $\sqrt{s}$ in the AGS energy domain, but it remains approximately constant at the SPS energies. At RHIC it seems to increase again. Data on K^- are similar. The main purpose of the present work is to see whether this behavior can be obtained within the hydrodynamic approach.

* Presented at the XXXIII International Symposium on Multiparticle Dynamics, Kraków, Poland, September 5–11, 2003.

[1] In [3], the entropy (and so the energy) has been associated with the multiplicity.

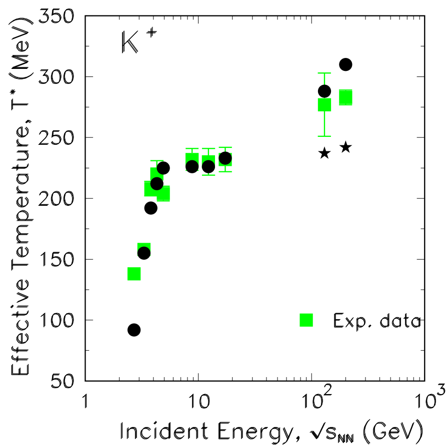

Fig. 1. Energy dependence of the inverse slope parameter for K^+. The initial conditions are IC-2. Stars correspond to $T_{\rm fo} = 155$ MeV.

2. Method of study

The main ingredients of any hydrodynamic approach are *(i)* the initial conditions; *(ii)* the equations of state; *(iii)* resolution of the hydrodynamic equations; and *(iv)* freeze-out conditions. We shall describe in the following each of these ingredients in our study.

Initial conditions: In [1], as an effective way to describe the $\sqrt{s}$ dependence of collisions, it has been proposed to use a Landau-type initial conditions [5], where at $t = 0$ fm the fluid is at rest and localized in a Lorentz contracted nuclear volume $V = \gamma_0^{-1} V_0 = \gamma_0^{-1}(4/3)\pi R^3$. The initial energy density is constant $\varepsilon_0 = E/V$, where $E = \zeta(\sqrt{s} - 2m)A$ is the kinetic energy available for production, ζ the inelasticity and $\gamma_0 = \sqrt{s}/2m$. Since it is well known that these initial conditions reproduce both particle multiplicities and the rapidity distributions, we took them as the first choice (IC-1).

We also used a second set of initial conditions, more spread at the initial time, with some longitudinal-dominant velocity distribution. For doing this, we used the NeXus event generator [6], which produces event-by-event fluctuating initial conditions at time $\tau = 1$ fm. Here we smoothed them out by averaging 30 random events for each collision energy (IC-2).

Equations of state: We consider two sets of equations of state, both having a first-order phase transition. The first one (EoS-1) is that proposed in [1], namely, an ideal gas of massless quarks (u, d and s) and gluons for QGP, and an ideal hadron gas, with an effective number of degrees of freedom $g_h = 16$, and baryon number assumed to be zero.

The second set (EoS-2) also considers an ideal massless quark-gluon gas for QGP, but is somewhat more realistic, taking the baryon number into account, and in the hadron phase all the resonances with mass below 2.5 GeV, with volume correction [7].

Resolution of hydrodynamic equations: We solve the hydrodynamic equations by using the previously developed numerical code SPheRIO[2] [8]. This is based on a technique called Smoothed Particle Hydrodynamics, which uses Lagrangian coordinates, well suited for treating fast expanding systems.

Freezeout conditions: Just for simplicity, here we use the usual Cooper–Frye prescription [9]. However, the freezeout temperature $T_{\rm fo}$ is not an intrinsic thermodynamic property of the fluid. It depends also on the system size. A rough estimate [10] gives $T_{\rm fo} \propto (\sqrt{s})^{-1/12}$, when $\sqrt{s} \to \infty$ for a given pair of nuclei, and which is verified in pp and $\bar{p}p$ data analyses.

3. Results

We started with IC-1 and EoS-1. This combination gave too large T^* in the whole region. The reason is that since initially the fluid is at rest, it takes a long time to cool, causing a large transverse expansion. A change to EoS-2 does not help, because they are similar in the QGP phase. We also tried to give the fluid some initial longitudinal velocity distribution, keeping the same V and E, but in this case, the multiplicity became too small.

TABLE I

Results obtained with IC-2. T_0 and ε_0 are the initial values at the midpoint of the fluid. $\bar{v}_{\rm T}$ is the averaged transverse velocity in $-0.5 \leq y \leq 0.5$.

$\sqrt{s}$ (A·GeV)	T_0 (MeV)	ε_0 (GeV/fm^3)	$T_{\rm fo}$ (MeV)	$\bar{v}_T$	T^* (MeV)
2.7	98	0.75	85	0.067	92
3.3	128	0.66	94	0.28	155
3.8	131	1.01	97	0.41	192
4.3	135	1.38	115	0.37	212
4.9	140	1.55	120	0.39	225
8.8	198	4.06	144	0.31	226
12.3	248	9.04	147	0.32	226
17.3	265	11.37	148	0.33	233
130	281	13.22	128	0.54	288
	290	14.80	155	0.35	237
200	288	14.54	125	0.57	310
	299	16.72	155	0.37	242

[2] **S**moothed **P**article **h**ydrodynamic **e**volution of **R**elativistic heavy **IO**n collisions.

Next, we considered IC-2 and this time using EoS-2. Some characteristics of the initial conditions generated are listed in Table I, together with the freezeout parameter $T_{\rm fo}$ and the results $\bar{v}_T$ and T^*. The latter is plotted as function of the incident energy in Fig. 1. As seen, the data at AGS and SPS are well reproduced with reasonable choices of $T_{\rm fo}$. As for the RHIC domain, our analysis favors freezeout occurring at much lower temperature than $T_{\rm c}$, and decreasing with energy, in accordance with [10].

4. Conclusions

The results presented in Sec. 3 give a strong support to the deconfinement transition occurring in Pb+Pb or Au+Au collisions approximately at the onset of SPS energies. The Landau-type initial conditions cannot reproduce T^* data, which means that the matter does not show thermodynamic behavior at $\tau \lesssim 1$ fm. The increase in T^* at RHIC seems to be due mostly to the larger expansion in the hadronic phase rather than to that in QGP.

This work was partially supported by FAPESP (Contracts: 2001/09861-1 and 2000/04422-7).

REFERENCES

[1] M. Gaździcki, M.I. Gorenstein, *Acta Phys. Pol. B* **30**, 2705 (1999).

[2] M.I. Gorenstein, M. Gaździcki, K.A. Bugaev, *Phys. Lett.* **B567**, 175 (2003).

[3] L. Van Hove, *Phys. Lett.* **B118**, 138 (1982).

[4] L. Ahle *et al.*, *Phys. Lett.* **B490**, 53 (2000); S.V. Afanasiev *et al.*, *Phys. Rev.* **C66**, 054902 (2002); D. Ouerdane *et al.*, `nucl-ex/0212001`; C. Adler *et al.*, `nucl-ex/0206008`.

[5] S.Z. Belenkij, L. Landau, *Usp. Fiz. Nauk* **56**, 309 (1955).

[6] H.J. Drescher, M. Hladik, S. Ostapchenko, T. Pierog, K. Werner, *Phys. Rep.* **350**, 93 (2001); H.J. Drescher, F.M. Liu, S. Ostapchenko, T. Pierog, K. Werner, *Phys. Rev.* **C65**, 054902 (2002).

[7] G.D. Yen, M.I. Gorenstein, W. Greiner, S.N. Yang, *Phys. Rev.* **C56**, 2210 (1997); C.M. Hung, E.V. Shuryak, *Phys. Rev.* **C57**, 1891 (1998).

[8] C.E. Aguiar, Y. Hama, T. Kodama, T. Osada, *J. Phys.* **G27**, 75 (2001); *Nucl. Phys.* **A698**, 639c (2002).

[9] F. Cooper, G. Frye, *Phys. Rev.* **D10**, 186 (1974).

[10] Y. Hama, F.S. Navarra, *Z. Phys.* **C53**, 501 (1992); F.S. Navarra, M.C. Nemes, U. Ornik, S.M. Paiva, *Phys. Rev.* **C45**, R2552 (1992).