Strongly interacting parton matter equilibration

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We study the kinetic and chemical equilibration in 'infinite' parton matter within the Parton-Hadron-String Dynamics transport approach. The 'infinite' matter is simulated within a cubic box with periodic boundary conditions initialized at different energy densities. Particle abundances, kinetic energy distributions and the detailed balance of the off-shell quarks and gluons in the strongly-interacting quark-gluon plasma are addressed and discussed.

1. INTRODUCTION

Nucleus-nucleus collisions at ultra-relativistic energies are studied experimentally and theoretically to obtain information about the properties of hadrons at high density and/or temperature as well as about the phase transition to a new state of matter, the quark-gluon plasma. The early 'big-bang' of the universe most likely evolved through steps of kinetic and chemical equilibrium. In contrast, the laboratory 'tiny bangs' proceed through phase-space configurations that initially are far from an equilibrium phase and then evolve by fast expansion. On the other hand, many observables from strongly-interacting systems are dominated by many-body phase space such that spectra and abundances look 'thermal'. It is thus tempting to characterize the experimental observables by global thermodynamical quantities like 'temperature', chemical potentials or entropy [1–8]. We note, that the use of macroscopic models like hydrodynamics [9–12] employs as basic assumption the concept of local thermal and chemical equilibrium. The crucial question, however, of how and on what timescales a global thermodynamic equilibrium can be achieved, is presently a matter of debate. In view of the increasing 'popularity' of thermodynamic analyses a thorough micro-

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scopic study of the questions of thermalization and equilibration of confined and deconfined matter within a transport approach appears necessary.

2. THE MODEL

In this contribution, we study the kinetic and chemical equilibration in 'infinite' parton-hadron matter within the novel Parton-Hadron-String Dynamics (PHSD) transport approach [13, 14], which is based on generalized transport equations on the basis of the off-shell Kadanoff-Baym equations [15, 16] for Green's functions in phase-space representation (in the first order gradient expansion, beyond the quasiparticle approximation). The basis of the partonic phase description is the dynamical quasiparticle model (DQPM) [17, 18] matched to reproduce lattice QCD results – including the partonic equation of state – in thermodynamic equilibrium [15]. The transition from partonic to hadronic degrees of freedom and vice versa is described by covariant transition rates for fusion of quark-antiquark pairs or three quarks (antiquarks), obeying flavor current conservation, color neutrality as well as energy-momentum conservation.

The 'infinite' matter is simulated within a cubic box with periodic boundary conditions. The size of the box is fixed to 9^3 fm^3. The initialization is done by populating the box with light (u, d, s) quarks, antiquarks and gluons with random space positions and the momenta distributed according to the Fermi-Dirac distribution. The total numbers of the quarks and antiquarks are chosen so that the system with various desired values of the energy density ε (the total energy of the particles divided by the size of the box) and baryon potential μ can be studied.

In the course of the subsequent transport evolution of the system by PHSD, the numbers of gluons, quarks and antiquarks are adjusted dynamically through the inelastic collisions to equilibrium values, while the elastic collisions lead to eventual thermalization of all the particle species (e.g. u, d, s quarks and gluons, if the energy density in the system is above critical). Please note that if the energy density in a local cell drops below critical either due to the local fluctuations or because the system was initialized with a low enough number of partons, a transition from initial pure partonic matter to hadronic degrees of freedom occurs dynamically by interactions (and vice versa).

3. RESULTS

In Fig. 1(a), we show a snapshot of the systems that has been initialized at an energy density of 2.18 GeV/fm^3, which is clearly above the critical energy density. One can see in Fig. 1(a) the spatial distribution of light quarks and antiquarks (circles), strange quarks and antiquarks (stars) and gluons (triangles) at a time of 40 fm/c. At this energy density no hadrons are seen. The different parton species are randomly distributed in space.

In Fig. 1(b) the reaction rates for elastic parton scattering (solid), gluon splitting (dash-dot) and flavor neutral $q\bar{q}$ fusion (dash) are presented as a function of time for a system initialized at an energy density of 2.87 GeV/fm^3. After a few fm/c the system has achieved chemical and thermal equilibrium, since the reactions rates are practically constant and obey detailed balance for gluon splitting and $q\bar{q}$ fusion.

Another indication that the system has achieved the thermal equilibrium is seen in the distribution of the kinetic energy of the particles. We show in Fig. 2(a) the energy spectra for the off-shell u (solid) and s quarks (dash) and gluons (dash-dot) in equilibrium for a system initialized at an energy density of 5.37 GeV/fm^3. The spectra may well be described by a Boltzmann distribution with temperature T=240 MeV in the high energy regime. The deviations from the Boltzmann distribution at low energy E are due to the broad spectral functions of the partons.

On the other hand, a sign of the *chemical* equilibration is the stabilization of the abundances of the different species. In Fig. 2(b), we show the particle abundances as a function of time for a system initialized at 9.43 GeV/fm^3. One can see that the chemical equilibration is reached after about 15 fm/c.

4. CONCLUSIONS

We have studied the kinetic and chemical equilibration in 'infinite' parton-hadron matter within the Parton-Hadron-String Dynamics transport approach (PHSD), which is based on a dynamical quasiparticle model for partons (DQPM) matched to reproduce lattice-QCD results – including the partonic equation of state – in thermodynamic equilibrium.

The 'infinite' matter has been simulated within a cubic box with periodic boundary conditions initialized at different energy densities. The system evolved into an ensemble of partons in chemical and thermal equilibrium. The temperature of the degrees of freedom in the final state was measured by fitting the slopes of the Boltzmann-like tails of the thermal distributions of their kinetic energy.

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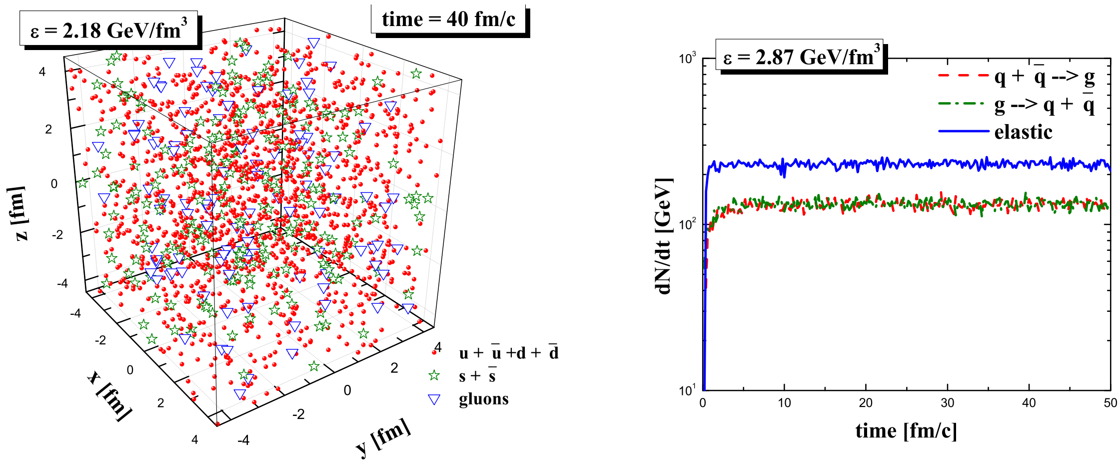

Figure 1. a) Snapshot of the spatial distribution of light quarks and antiquarks (circles), strange quarks and antiquarks (stars) and gluons (triangles) at a time of 40 fm/c. b) The reaction rates for elastic parton scattering (solid), gluon splitting (dash-dot) and flavor neutral $q\bar{q}$ fusion (dash) as a function of time.

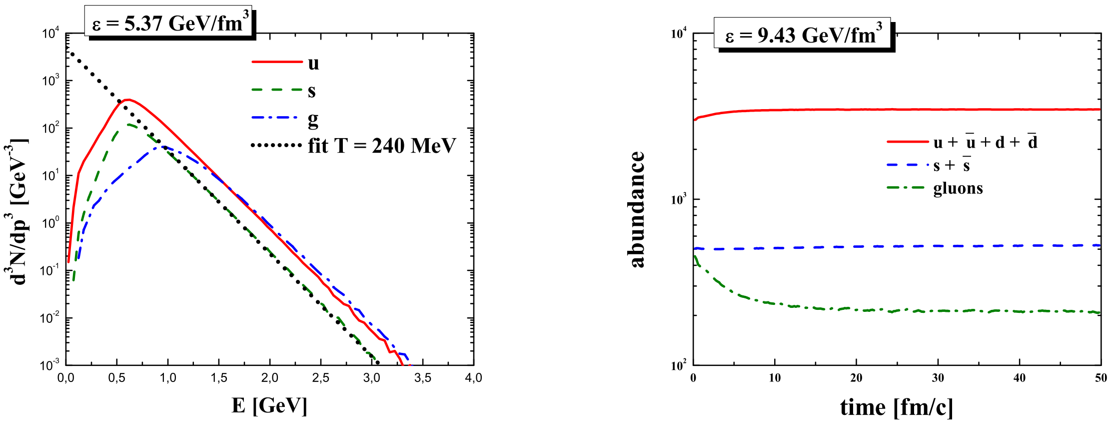

Figure 2. a) The energy spectra for the off-shell u (solid) and s quarks (dash) and gluons (dash-dot) in equilibrium for a system initialized at an energy density of 5.37 GeV/fm^3. b) Abundances of the u,d s quarks+antiquarks and gluons as a function of time for a system initialized at an energy density of 9.43 GeV/fm^3.

FIGURE CAPTIONS

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