THE EQUILIBRATION OF A PARTON PLASMA CREATED IN RELATIVISTIC HEAVY ION COLLISIONS

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Abstract

We study the equilibration of a parton plasma in terms of its parton compositions and its state of thermalization. In studying the evolution of the plasma, one has to assume a small value of the strong coupling constant. This value is by no means fixed. By varying this only parameter in our calculation, we show the dependence of equilibration on its magnitude. It is shown that both kinetic and parton equilibration are faster with increasing coupling but the plasma cools much more rapidly resulting in shortened lifetime. The degree of equilibration improves significantly for quarks and antiquarks but not so for gluons and the total generated entropy is reduced. With a coupling depending on the average parton energy, there is additional acceleration in the equilibration during the evolution.

1 Introduction

Equilibration in relativistic heavy ion collisions is an important problem because particle signatures upon which one relies for detecting the deconfined matter are directly influenced by the temporal development of the remnant of the initial collisions. The evolution of the so produced secondary partons will undergo many interactions and hence in accordance with the laws of thermodynamics, the plasma consisting of these partons will try to reach equilibrium. This process is not without hindrance and there is no guarantee that equilibrium can be reached. First because it is a highly compressed system at the beginning, it will try to push itself apart and therefore undergoes expansion, which is very disruptive for the equilibrating parton system. In order to equilibrate, the net interaction rate must dominate over the expansion rate. Second, time is limited because a sufficiently cooled system will not be able to resist the confining force which is also responsible for the equilibration process in the first place. In this talk, we would like to point out that the confining force actually helps the parton system to equilibrate before proceeding to change the very form of the components of the system through the deconfinement phase transition and hence ending the pure partonic equilibration process all together.

In previous studies of the equilibration, in chemical [1, 2] as well as in kinetic equilibration [3, 4, 5], the system evolved through a period of time varying from several fm/c to over 10 fm/c depending on the initial conditions. In this period, the estimated temperature dropped by hundreds of MeV and the average parton energy also decreased by over 1 GeV. So the system underwent significant changes. In these studies, a value of $\alpha_s = 0.3$ was used which is equivalent to an average momentum transfer of $Q \sim 2$ GeV and $\Lambda_{QCD} \sim 200$ MeV. But we have just pointed out that the average parton energy varies by so much that we cannot reasonably expect the average $Q$ to remain at 2 GeV. So during the evolution of the plasma, the strength of the interaction is also likely to evolve with the system. We shall try to take this into account. A second point also related to the coupling in the question of the equilibration of the parton plasma is the
Figure 1: The variations of the fugacities and the estimated temperatures with time and $\alpha_s$. Solid, dotted, dashed and long dashed lines are for $\alpha_s = 0.3, 0.5, 0.8$ and $\alpha_s^v$ respectively. (a) for gluon and (b) for quark at LHC and (a'),(b') are the same at RHIC.

fact that due to screening and the generation of medium masses in a dense environment [6], no arbitrary infrared cutoff is required in the calculation. Therefore $\alpha_s$ is the only parameter, apart from the obvious initial conditions, that one can choose. We would like to find out how the results will be affected by the choice of $\alpha_s$. Also, as we have just mentioned, if we relate the coupling to the average momentum transfer of the system then even $\alpha_s$ is determined by the system and no other parameter other than the initial conditions remain.

We shall use different values of $\alpha_s$ and in addition we also assume $Q$ to be given by the average parton energy and use the one-loop formula $\alpha_s(Q) = \frac{4\pi}{\beta_0 \ln(Q^2/\Lambda_{QCD}^2)}$ to obtain a time-dependent coupling which varies as the system evolves [7]. We shall refer to this coupling in the following as $\alpha_s^v$. The results of this evolution are then compared with those obtained with fixed $\alpha_s$.

2 The Evolution of a parton plasma with different couplings

In order to determine the effects of the variation of $\alpha_s$ on the equilibration. We choose values of $\alpha_s = 0.5, 0.8$ and $\alpha_s^v$ in addition to $\alpha_s = 0.3$ [5, 7]. Such large values of $\alpha_s$ are chosen deliberately to make the effects manifest. We are not after quantitative but rather qualitative results. In any case, the uncertainties in the initial conditions do not permit us to make any meaningful numerical predictions at present. Such uncertainties will not concern us here, we concentrate rather on the coupling. With the same initial HIJING inputs [8] as before, the evolution is performed using the method described in [7].

To check the state of the equilibration, we look at the parton fugacities $l$, the longitu-
Figure 2: The variations of the ratios of longitudinal and a third of the energy density to transverse pressure with time and $\alpha_s$. Solid, dotted, dashed and long dashed lines are for $\alpha_s = 0.3, 0.5, 0.8$ and $\alpha_s^\nu$ respectively.

dinal to transverse pressure ratios $p_L/p_T$ and the temperature estimates $T$. The first give us information about the partonic composition of the plasma, the second reveal the state of the kinetic equilibration of the system and the last tell us about the possible lifetime of the parton plasma. These are plotted in Fig. 1 and Fig. 2.

Let us first look at the partonic composition of the plasma as a function of time. These are shown in Fig. 1 (a),(b) for LHC and (a’),(b’) for RHIC in terms of fugacities. The curves shift towards the left upper corner with increasing coupling. As can be seen, more prominent in the case of quark and antiquark than that of gluon, chemical equilibration is faster with increasing coupling. The final $l_g$ for gluon are approximately the same, but for quark and antiquark, larger $\alpha_s$ does make a difference in the final $l_q$. A factor of 1.76 or more has been gained both at LHC and at RHIC.

Turning to kinetic equilibration of the parton, we show the degree of isotropy of the momentum distribution of each parton component. This is done in terms of the ratio of the longitudinal to transverse pressure. These plots are shown in Fig. 2 (a),(b) for LHC and (a’),(b’) for RHIC. With increasing $\alpha_s$, the curves shift upwards, that is closer to kinetic equilibrium or isotropic momentum distribution. The final degree of kinetic equilibration for gluon is, like $l_g$, again approximately the same. That for quark and antiquark is again much obvious and shows improvement. The top set of curves in each plot is used as a double check which are plots of $\epsilon/3p_T$. These ratios should all go to 1.0 at equilibrium. It now becomes obvious that larger $\alpha_s$ speeds up equilibration for both quark and gluon, but only quark and antiquark show signs of much obvious improvements in the degree of equilibration. All these are at the expense of shorter lifetime as one can see the curves with larger $\alpha_s$ are stopped at earlier times. This is because the temperature estimates of the partons drop faster with increasing $\alpha_s$. This is also plotted in Fig. 1.
The effect of larger $\alpha_s$ is to reduce the lifetime but speed up equilibration. Only quark and antiquark show significant improvements but not gluon. We are especially interested in the case of $\alpha_s^\nu$ because as stated in the introduction, the coupling should be affected by the evolution of the plasma. As seen in the figures, the results start off staying close to those of $\alpha_s = 0.3$ but very soon depart and shift across the constant $\alpha_s$ “contours”. So we see that with a time-dependent coupling as determined by the system, there is an acceleration effect. As mentioned earlier, the confining force helps the equilibration process but at a price of earlier onset of the deconfinement phase transition.

Different strengths of the interactions also affect the generated entropy. Larger $\alpha_s$ increases the gluon entropy loss by gluon conversion into quark and antiquark pairs. As we have seen the faster equilibration of quark and antiquark, which leads also to a reduction in their generated entropy. The tendency is then a reduced total entropy and hence a reduced final pion multiplicity. If there is a first order phase transition, the mixed phase will also be shortened.

In summary, we have seen that larger coupling has much more obvious effects on the degree of equilibration of quarks and antiquarks than on gluons. Significant improvement in the case of quarks and antiquarks but not in that of gluons. Both the lifetime and the total generated entropy are sensitive to the strength of the interactions. A time-dependent coupling based on the actual situation of the system will lead to accelerated equilibration but the earlier arrival of the deconfinement phase transition.

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**References**

[1] T.S. Biró, E. van Doorn, B. Müller, M.H. Thoma and X.N. Wang, Phys. Rev. C 48, 1275 (1993); P. Lévai, B. Müller and X.N. Wang, Phys. Rev. C 51, 3326 (1995); X.N. Wang, Nucl. Phys. A 590, 47 (1995).

[2] E.V. Shuryak and L. Xiong, Phys. Rev. C 49, 2203 (1994).

[3] E.V. Shuryak, Phys. Rev. Lett. 68, 3270 (1992).

[4] K. Geiger and B. Müller, Nucl. Phys. B 369, 600 (1991); K. Geiger, Phys. Rev. D 46, 4965, 4986 (1992); K. Geiger and J.I. Kapusta, Phys. Rev. D 47, 4905 (1993).

[5] S.M.H. Wong, Nucl. Phys. A 607, 442 (1996); Phys. Rev. C 54, 2588 (1996).

[6] V.V. Klimov, Yad. Fiz. 33, 1734 (1981), Sov. J. Nucl. Phys. 33, 934 (1981), A.H. Weldon, Phys. Rev. D 26, 1394,2789 (1982).

[7] S.M.H. Wong, preprint WU B 97/13, to appear in Phys. Rev. C.

[8] M. Gyulassy and X.N. Wang, Phys. Rev. D 44, 3501 (1991); M. Gyulassy, M. Plümer, M. Thoma and X.N. Wang, Nucl. Phys. A 538, 37c (1992); M. Gyulassy and X.N. Wang, Nucl. Phys. A 544, 559c (1992).