Baryon Number Fluctuation and the Quark-Gluon Plasma

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Because of the fractional baryon number of quarks, baryon and antibaryon number fluctuations in the quark-gluon plasma is less than those in the hadronic matter, making them plausible signatures for the quark-gluon plasma expected to be formed in relativistic heavy ion collisions. To illustrate this possibility, we have introduced a kinetic model that takes into account both production and annihilation of quark-antiquark or baryon-antibaryon pairs [1].

In the case of only baryon-antibaryon production from and annihilation to two mesons, i.e., $m_1 m_2 \leftrightarrow B\overline{B}$, we have the following master equation for the multiplicity distribution of $B\overline{B}$ pairs:

$$\frac{dP_n}{d\tau} = \frac{G}{V}\langle N_{m_1}\rangle\langle N_{m_2}\rangle\,(P_{n-1}-P_n) - \frac{L}{V}\left[n^2 P_n - (n+1)^2 P_{n+1}\right]. \quad (1)$$

In the above, $P_n(\vartheta)$ denotes the probability of finding n pairs of $B\overline{B}$ at time ϑ; $G \equiv \langle\sigma_G v\rangle$ and $L \equiv \langle\sigma_L v\rangle$ are the momentum-averaged cross sections for baryon production and annihilation, respectively; N_k represents the total number of particle species k; and V is the proper volume of the system.

The equilibrium solution to Eq. (1) is [2]

$$P_{n,\mathrm{eq}} = \frac{\epsilon^n}{I_0(2\sqrt{\epsilon})\,(n!)^2}, \quad (2)$$

with

$$\epsilon \equiv \frac{G\langle N_{m_1}\rangle\langle N_{m_2}\rangle}{L}, \quad (3)$$

and I_0 being the modified Bessel function.

Using the generating function at equilibrium,

$$g_{\mathrm{eq}}(x) \equiv \sum_{n=0}^{\infty} P_{n,\mathrm{eq}}x^n = \frac{I_0(2\sqrt{\epsilon x})}{I_0(2\sqrt{\epsilon})}, \quad (4)$$

with $g(l) = \sum P_n = 1$ due to normalization of the multiplicity probability distribution, it is straightforward to obtain all moments of the equilibrium multiplicity distribution. In terms of the fundamental unit of baryon number b_o in the matter, the mean baryon number per event is given by

$$\langle B\rangle_{\mathrm{eq}} = b_0\sqrt{\epsilon}\frac{I_1}{I_0} \simeq b_0\sqrt{\epsilon}, \quad (5)$$

while the squared baryon number fluctuation per baryon at equilibrium is given by

$$\omega_{B,\mathrm{eq}} = b_0\left[1-\sqrt{\epsilon}\left(\frac{I_1}{I_0}-\frac{I_2}{I_1}\right)\right] \simeq \frac{b_0}{2}. (6)$$

In obtaining the last expressions in Eqs. (5) and (6), we have kept only the leading term in $\sqrt{\mathrm{E}}$ corresponding to the grand canonical limit, $\sqrt{\mathrm{E}} \gg 1$, as baryons and antibaryons are abundantly produced in heavy ion collisions at RHIC. Since b_o is 1/3 in quark-gluon plasma and 1 in hadronic matter, w_B is smaller in the quark-gluon plasma than in an equilibrated hadronic matter by a factor of 3.

We note that the equilibrium multiplicity distribution in Eq. (2) is not Poisson. Furthermore, $T_{B,eq}$ has a value of $b_o/2$ instead of the naive value of b_o, that is expected from a Poisson multiplicity distribution. The non-Poisson distribution results from the quadratic dependence on the multiplicity n in the loss term of the master equation of Eq. (1) due to baryon number conservation. A Poisson distribution is obtained if the dependence on the multiplicity n is linear, which corresponds to production of particles that do not carry conserved charges. We also note that the master equation of Eq. (1) gives a Poisson distribution at early times ($\vartheta \rightarrow 0$) when the loss term can be neglected. This corresponds to either production of particles with conserved U(I) charges during the early stage of heavy ion collisions or particle production without chemical equilibration as in e^+e^- collisions.

Because of experimental limitations, only protons and antiprotons in a certain rapidity and momentum range are usually measured. Moreover, the net baryon number in heavy ion collisions is in general non-zero even at mid-rapidity due to the presence of projectile and target nucleons. Using a generalized master equation that includes these effects, we have shown that the above results remain essentially unchanged.

Unlike the net baryon number fluctuation proposed in Ref. [3] and the net charged particle fluctuation proposed in Ref. [4], baryon and antibaryou number fluctuations are non-zero in the full phase space and are not affected by elastic scatterings. Although inelastic reactions such as baryon-antibaryon pair production and annihilation tend to reduce their sensitivity to the quark-gluon plasma by driving their values towards those from an equilibrated hadronic matter, the large baryon masses make it unlikely that baryon and antibaryon production is important in the final hadronic stage of ultra-relativistic heavy ion collisions. On the other hand, baryon-antibaryon production during the hadronization from the quark-gluon plasma to the hadronic matter affects the baryon and antibaryon number fluctuations, in ways similar to that due to baryon and antibaryon inelastic scatterings. To study this effect requires knowledge about the hadronization process, which is at present not well understood.

References

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