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Effects of Particle Distribution on the Rates of s-Quark and K⁻-Meson Production

Zhou Baosen and He Zejun

Shanghai Institute of Nuclear Research, Chinese Academy of Sciences, Shanghai, China

Based on the model of the expanding hot quart-gluon plasma fireball created in ultrarelativistic heavy-ion collisions, we investigated the rates of the s-quark and K^--meson productions after considering particle distribution in the fireball and by using the relativistic hydrodynamic equation. It is shown that the particle distributions enhance the production rates strongly.

It is generally believed that inside some celestial bodies such as neutron stars, or during the ultrarelativistic heavy-ion collisions, a new nuclear matter state [1,2], namely the quark-gluon plasma, might be formed. The K^--meson which contains an s-quark may carry important information on the QGP [3,4], hence it becomes an important way to verify the existence of the QGP.

The experiments at the AGS in BNL, U.S.A. showed that the Si ions with bombarding energy 14.5 GeV/u can be fully stopped by another heavy ion whose mass number A is larger than 100 [2]. Based on this fact, in this work we assume that a high temperature (not less than 200 MeV), high density (about 4 times of normal nuclear matter density) fireball is composed mainly by the quark-gluon plasma. We think that the mean free path of the particle is much less than the range of length of the fireball, so that the whole system can quickly approach a local equilibrium inside the fireball. From this point of view, we can adopt a relativistic hydrodynamic equation to describe the evolution of the system [5-7],

$$\partial_\mu T^{\mu\nu} = 0, \tag{1}$$

where $T^{\mu\nu}$ is the energy-momentum tensor. It is different from the initial scaling equation developed by Bjorken [13].

For the phase transition picture of the system from the quark-gluon phase to the hadronic one with a temperature dropping, we adopt a supersonic condensation model [8]. The influences of latent

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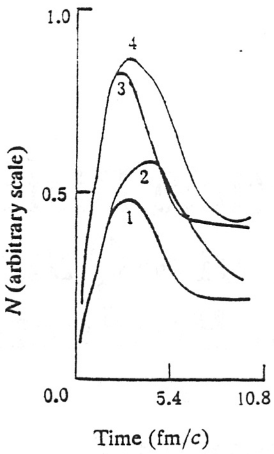

Fig. 1
Time evolution of the total number of the s-quark and K^--meson in the system. The meanings of label 1-4 are explained in the text. The initial temperature of the system is T_0 = 230 MeV.

heat on the temperature at the phase transition interface are also considered. We think that the main component is the π-meson in the initial period of hadronic phase [9], so the basic processes in which the π-mesons annihilate to create the K^--mesons, such as $\pi^+\pi^- \rightarrow K^+K^-$, $\pi^-\pi^0 \rightarrow K^-K^0$, $\pi^0\pi^0 \rightarrow K^+K^-$, are considered.

For the s-quark and K^--meson production, Müller *et al.*, by ignoring the spatial distribution of temperature [10], and Kapusta [11], by using the Bjorken model, obtained the time- dependent result. The s-quark and K^--meson productions were further studied by taking the spatial distribution of temperature into account [12] and it was found that this distribution cannot be omitted.

As to the very high temperature system, by using the Boltzmann approximation of the distribution function, i.e., $f(p) = \exp(-E/T)$, Kapusta and Mekjian [11] gave the parameterized forms of the strangeness production rates $R_q(T)$ and $R_h(T)$ corresponding to the quark phase and hadronic phase, respectively (here p, E and T denote the momentum, energy and temperature, respectively, and $\hbar = c = k = 1$). But this eliminated the correlations between the distribution function and particle number density. In order to consider the influences of the particle distributions in space-time on the dilepton mass spectrum, He *et al.* [7] employed a complete Boltzmann approximation of the distribution function, $f(p) = \rho\exp(-E/T)$, where ρ is the particle number density. A similar approximation was used in the study of nucleon spectra by the fireball model by Bondorfin *et al.* [14]

Therefore, we study the effects of the particle distributions on the s-quark and K^--meson production rates. Obviously, various particle number distributions would lead to very different strangeness production rates. In order to find out the particle occupation number distributions at every point, we should solve the following equation of continuity

$$\partial_t(\rho\cosh\eta) + \frac{1}{r^2}\,(r^2\sinh\eta) = 0, \tag{2}$$

where η is the transverse velocity and r the fireball radius. Therefore, the s-quark or K^--meson production rate with the effects of particle number distributions can be described as

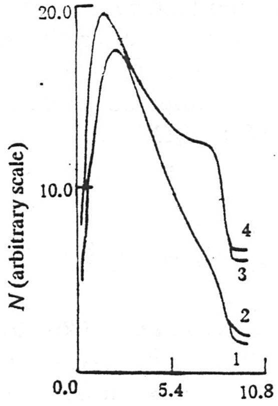

Fig. 2
The same as Fig. 1, except for the initial temperature T_0 = 500 MeV.

$$R(T(r,t),\rho(r,t)) = \rho_1 c_1 R_{q(\text{ or } h)}(T) c_2 \rho_2, \tag{3}$$

where the subscript 1 denotes particles, 2 the antiparticles, constants c_1 and c_2 are related to the total particle numbers in whole space-time.

To ascertain the evolution picture of the strangeness (s-quark, K^--meson), we use the relaxation equation as follows [11,12]:

$$\frac{dn}{dt} = R(T(r,t), \rho(r,t)) \left[1 - \left(\frac{n}{n_{eq}}\right)^2\right], \tag{4}$$

where n is the particle number density of the s-quark ($T < T_c$) or the K^--meson($T > T_c$) and n_{eq} is the equilibrium density which can be obtained from the Boltzmann statistics.

Assuming that the initial temperature of the fireball is T_0 = 230 MeV and critical phase transition temperature is T_c = 160 MeV, and including other parameters, we solve equations (1)-(4) so that the mean free path of the particles is comparable with the length of the fireball. The calculated total number of the s-quarks and K^--mesons is shown in Fig. 1 as a function of the evaluation time. The curves in Fig. 1 correspond to different approximations. Curve 1 is the result of ignoring the effects of both the particle distribution and the latent heat on the s-quark and K^--meson production rates. Curve 2 is the result with the effects of the latent heat. In curve 3, the particle distribution is considered. The result by considering both the particle distribution and the latent heat is presented in curve 4.

It is obvious that the s-quark and K^--meson production rates are enhanced due to the release of the latent heat. Since the heat transports both outwards and inwards, the temperature of the whole system is increased. One the other hand, the high temperature in the inner part of the system prevents the quarks from moving outwards. As a result, the occupation number of particles in the center region is higher. This further enhances the strangeness production rate.

In order to highlight the effects of the particle number distribution on the s-quark and K^--meson production rates, we show in Fig. 2 another set of data under the same condition, except that the initial temperature is T_0 = 500 Mev. It is clear that when the initial temperature is much higher, the effect of latent heat becomes less important, but the particle number distribution can still enhance the s-quark and K⁻-meson production rates to a certain extent.

To sum up, the particle distributions enhance the s-quark and K⁻-meson production rates significantly. This is an important factor to be considered for the investigation of the s-quark and K⁻-meson productions during the evolution of the QGP.

REFERENCES

[1] G.F. Chaplin and M. Nauenberg, *Nature*, **264** (1976) 235.
[2] S. Nagamiya, *Nucl. Phys.*, **A488** (1988) 3c.
[3] P. Koch, B.Müller and J. Refelski, *Phys. Rep.*, **142** (1986) 167.
[4] U. Heinz, K. S. Lee and M. J. Rhodes-Brown, *Phys. Rev. Lett.*, **58** (1987) 2297.
[5] J. Kapusta, Quark Matter Formation and Heavy-ion Collisions (Proceeding of the Bieleted Workshop, May 1982) 115.
[6] L. D. Landau and F. M. Lifshiz, 1959, *Course of Theoretical Physics*, Vol. 6, anth. trans from Russian, J. B. Sykes and W. H. Reid ch xv (Oxford:Pergaman).
[7] He Zejun, Zhang Jiaju, Li Panlin and Qiu Xijun, *J. Phys. G: Nucl. Part. Phys.*, 19 (1990) L179.
[8] S. P. Baranov and L. V. Fil'kov, *Z. Phys.*, **C44** (1989) 227.
[9] C. M. Ko and L. H. Xia, *Nucl. Phys.*, **A498** (1989) 561c. In this paper, the produced numbers of π, K, N, as well as other mesons and hadrons in hadronic phase were given out. One can find the main contribution is from π-meson.
[10] B. Müller and J. Refelski, *Phys. Rev. Lett.*, **D48** (1982) 1066.
[11] J. Kapusta, A. Mekjian, *Phys. Rev.*, **D33** (1086) 1304.
[12] Debao Jang, Zejun He, The Strangeness production in Ultrarelativistic heavy-ion Collisions, *High Energy Physics and Nuclear Physics*, to be published.
[13] J. D. Bjorken, *Phys. Rev.*, **D27** (1982) 140.
[14] J. P. Bondorf, S. T. A. Garpman and J. Zimanyi, *Nucl. Phys.*, **A296** (1978) 320.