# $K/\pi$ ratio as a signal of the formation of a quark-gluon plasma in heavy-ion collisions

V. M. Emel'yanov
*Engineering-Physics Institute, Moscow*

(Submitted 14 March 1988)
Pis'ma Zh. Eksp. Teor. Fiz. **47**, No. 10, 491–493 (25 May 1988)

The formation of singlet quark-gluon plasma droplets 1–2 fm in size in ion-ion collisions is shown to give a multiplicity ratio $K/\pi \approx 0.05$ for $dN^{\pi}/dy \sim 100$.

The collision of $O^{16}$ and $S^{32}$ nuclei (at $\sim 200$ GeV/nucleon) with heavy nuclei is now being studied experimentally by six international collaborations at CERN. The purpose of these experiments is to detect the formation of a quark-gluon plasma.[1-3] The structural features of the dilepton spectra[4-6] and the enhancement of the strange-particle yield are some of the quark-gluon-plasma signals that are receiving most attention. The possibility of enhancing the strange-particle yield has long been discussed in the literature.[7,8] This idea is based on the fact that nonstrange-antiquark production in a quark-gluon plasma is suppressed because of the Pauli principle and the fact that there is no such suppression in the case of strange antiquark production. In events involving the production of a quark-gluon plasma the ratio of the multiplicities of $K$ and $\pi$ mesons is therefore expected to increase; $K/\pi \approx 0.2$–$0.3$ (Ref. 9). An increase in the ratio $K/\pi$ (as a function of the energy of the colliding particles, for example) has been viewed for some time as a signal of the formation of the quark-gluon plasma. In several recent experimental studies[10] it has been shown, however, that the ratio $K/\pi \approx 0.2$–$0.3$ can also be obtained in a hadron gas by properly taking into account the kinetics of the $K$- and $\pi$-meson production. This circumstance explains to a large extent the attention given to the ratio $K/\pi$ as a signal of the formation of a quark-gluon plasma.

A quark-gluon plasma is generally taken to mean an ideal gas of quarks, antiquarks, and gluons extending a distance of $\gtrsim 1$ fm. At gas temperatures $T \sim T_c \approx 200$ MeV [at the "hadrons-(quark-gluon plasma)" phase-transition temperature], however, the gas should exhibit pronounced nonperturbation-theory QCD effects. Unfor-

 0021-3640/88/100575-04$01.00  

tunately, the nonperturbation-theory QCD sector has not been studied thoroughly. The only feature that has perhaps been positively determined is that color does not escape. It is, therefore, reasonable to assume that if quark and gluon deconfinement occurs in ion-ion collisions and a quark-gluon plasma is formed, then a quark-gluon plasma would be produced in a finite volume $V=\frac{4}{3}\pi R^3$ at a temperature $T$, and the global state of the quark-gluon plasma in a volume $V$ would be a singlet with respect to the transformations from the $SU(3)_c$ group.[11] In this letter we will consider the effect of the condition under which the quark-gluon plasma is of a singlet nature on the dynamics of the production of strange quarks (antiquarks).

The singlet nature of quark-gluon plasma alters the momentum distribution of quarks, antiquarks, and gluons[11]:

$$f_{q(\bar{q})}(k,R,T) = \frac{2k^2}{\pi^2}\left(1-\frac{1}{2(kR)^2}\right)\sum_{m=0}^{\infty}(-1)^m e^{-k(m+1)/T} e^{-(m+1)^2[(k^2/4DT^2)+(1/3C)]} \quad (1)$$

$$f_g(k,R,T) = \frac{k^2}{\pi^2}\left(1-\frac{2}{(kR)^2}\right)\sum_{m=0}^{\infty} e^{-k(m+1)/T} e^{-(m+1)^2[(k^2/4DT^2)+(1/C)]}, \quad (2)$$

where

$$k=|\mathbf{k}|,\; C=\frac{32}{9}\pi R^3T^3+\frac{20}{3\pi}RT, \qquad D=\frac{148}{135}\pi^3R^3T^3-\frac{38}{27}\pi RT.$$

For $RT\gg 1$ we find from relations (1) and (2) respectively the Fermi and Bose distributions for quarks and gluons. We see from relations (1) and (2) that the gluon functions $f_g(k,R,T)$ are most sensitive to the imposition of the singlet condition.

Let us consider the production of strange $s\bar{s}$ quark pairs in a quark-gluon plasma. There are two channels for the production of $s\bar{s}$ pairs: 1) two-gluon annihilation $gg\to s\bar{s}$ and 2) light-quark annihilation $u\bar{u}\to s\bar{s}$ and $d\bar{d}\to s\bar{s}$. The rate of production of $s\bar{s}$ pairs (i.e., the number of $s\bar{s}$ pairs produced per unit time per unit volume of a quark-gluon plasma) has two components $A(R,T)=A_{gg\to s\bar{s}}+A_{q\bar{q}\to s\bar{s}}$, where

$$A_{gg\to s\bar{s}}(R,T) = \frac{4}{\pi^4}\int_{4m_s^2}^{\infty} dS\cdot S\sigma_{gg\to s\bar{s}}\left[\int_0^{\infty} dk_1\int_0^{\infty} dk_2\,\theta(4k_1k_2-S)f_g(k_1,R,T)f_g(k_2,R,T)\right], \quad (3)$$

$$A_{q\bar{q}\to s\bar{s}}(R,T) = \frac{9}{4\pi^4}\int_{4m_s^2}^{\infty} dS\cdot S\sigma_{q\bar{q}\to s\bar{s}}\left[\int_0^{\infty} dk_1\int_0^{\infty} dk_2\,\theta(4k_1k_2-S)f_q(k_1,R,T)f_{\bar{q}}(k_2,R,T)\right], \quad (4)$$

where $\sigma_{gg\to s\bar{s}}$ and $\sigma_{q\bar{q}\to s\bar{s}}$ are the cross sections[9] of the reactions $gg\to s\bar{s}$ and $q\bar{q}\to s\bar{s}$.

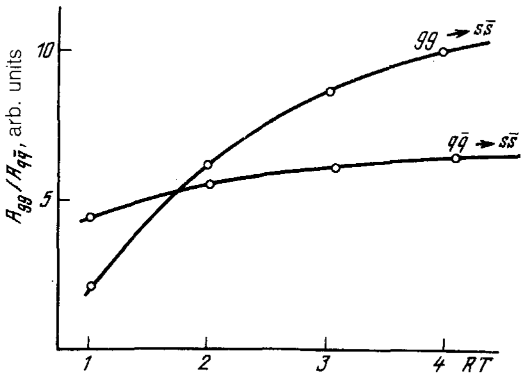


FIG. 1. Rates of production of $s\bar{s}$ pairs versus $RT$.

Figure 1 is a plot of the rates of the production of $A_{gg}$ and $A_{q\bar{q}}$ as a function of $RT$. We see in Fig. 1 that if the condition under which a quark-gluon plasma is of a singlet nature is not satisfied (i.e., if $RT \gg 1$), the total rate of the production of $s\bar{s}$ pairs is determined by the gluon annihilation ($A_{gg}/A_{q\bar{q}} \sim 3$–$4$). This result has been reported by Koch *et al.*[9] For $RT \approx 1$–$2$, however, the light quark and antiquark annihilation is the governing $s\bar{s}$ pair production channel, because gluon distributions (2) depend on $RT$ more critically than quark distributions (1). In the interval $1 \lesssim RT \lesssim 2$ the total rate of $s\bar{s}$ pair production increases by approximately a factor of two. The quark-gluon-plasma entropy density (relative to the Stefan-Boltzmann limit) with the distribution functions (1) and (2) is plotted in Fig. 2. It follows from Fig. 2 that the entropy density increases by approximately a factor of eight in the interval $1 \lesssim RT \lesssim 2$. It can be expected, therefore, that the ratio $K/\pi$, which is proportional to $(A_{gg} + A_{q\bar{q}})/S$ in the interval $1 \lesssim RT \lesssim 2$, would decrease by a factor of four. If a quark-gluon plasma is produced in a heavy-ion collision at temperatures $T \sim T_c \approx 0.2$ GeV, a radius of the singlet droplets of the quark-gluon plasma, R $\sim$ 1–2 fm, would correspond to the values of $RT \approx 1$–$2$. The value of $T$ could be related[12] to the density of charged particles

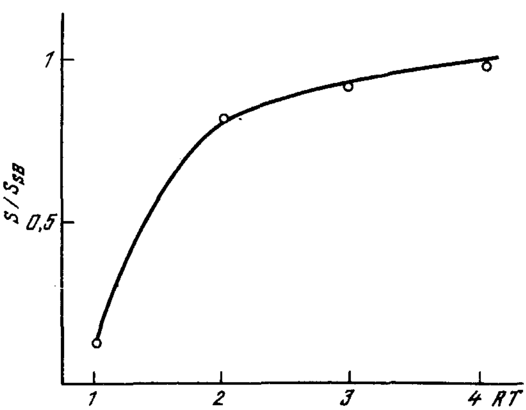


FIG. 2. Behavior of the entropy density of quark-gluon plasma (with respect to the Stefan-Boltzmann limit) versus $RT$.

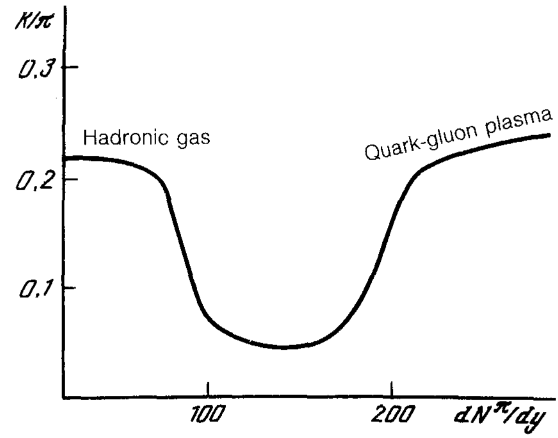


FIG. 3. The ratio $K/\pi$ versus the multiplicity $dn^{\pi}/dy$.

(pions), $dN^{\pi}/dy$. The values $RT \approx 1$–2 correspond to the densities $dN^{\pi}/dy \approx 100$–200. Accordingly, if quark-gluon-plasma singlet droplets of small size ($\sim 1$–2 fm) are formed in ion collisions, a minimum may appear in the plot of the ratio $K/\pi$ versus $dN^{\pi}/dy$, with $dN^{\pi}/dy$ lying in the interval $\sim 100$–200. In other words, for such multiplicities of $dN^{\pi}/dy$ the strange-particle ($K$-meson) yield would be suppressed (in comparison with $\pi$ mesons) by approximately a factor of four. If, on the other hand, quark-gluon plasma droplets of size $\gtrsim 2$ fm are formed at $T \sim T_c$, the entropy density (Fig. 2) would be virtually independent of $RT$ when $RT \gtrsim 2$, while the rate of $s\bar{s}$ quark production would be determined by the $gg \to s\bar{s}$ annihilation and would be an increasing function. In other words, for multiplicities of $dN^{\pi}/dy \gtrsim 200$ the strange-particle yield would be enhanced. A qualitative plot of the ratio $K/\pi$ versus $dN^{\pi}/dy$ is shown in Fig. 3. It would be desirable to have the *NA* 34 and *NA* 35 collaboration in CERN study the behavior of $(K/\pi)$ $(dN^{\pi}/dy)$ with the goal of determining the mechanisms involved in the formation of quark-gluon plasma in ion-ion collisions.

I wish to thank B. A. Dolgoshein, A. V. Vanyashin, S. A. Voloshin, Yu. P. Nikitin, and M. I. Gorenshteĭn for interest in this study and for discussions.

[1]A. M. Polyakov, Phys. Lett. **72B**, 477 (1978).
[2]L. Susskind, Phys. Rev. **D20**, 2610 (1979).
[3]E. Shuryak, Phys. Rep. **61**, 71 (1980).
[4]E. L. Faĭnberg, Izv. Akad. Nauk SSSR, ser. fiz., **26**, 622 (1962).
[5]G. Domokos and J. Goldman, Phys. Rev. **D23**, 203 (1981).
[6]E. Shuryak, Phys. Rep. **115**, 151 (1984).
[7]J. Rafelski and B. Müller, Phys. Rev. Lett. **48**, 1006 (1982).
[8]T. Biro and J. Zimanyi, Phys. Lett. **B113**, 6 (1982).
[9]P. Koch, B. Müller, and J. Rafelski, Phys. Rep. **142**, 167 (1986).
[10]T. Matsui, L. McLerran, and B. Svetitsky, Phys. Rev. **D34**, 783 (1986); **D34**, 2047 (1986).
[11]H. T. Elze and W. Greiner, Phys. Lett. B **131**, 385 (1986).
[12]R. Hwa and K. Kajantie, Phys. Rev. **D32**, 1109 (1985).

Translated by S. J. Amoretty