Strangeness Production in Excluded Volume Models

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Introduction

One of the most potential probes for detecting Quark-Gluon Plasma (QGP) formation in ultra-relativistic heavy-ion collision experiments is the observation of the abundance of strange particles. This is based on the proposal that in the baryon rich plasma, the strange quark-antiquark pairs $s\bar{s}$ would be more abundant than u, d quarks because of the lower threshold for $s\bar{s}$ pair production ($\approx$ 300 MeV) in QGP than that for $K\bar{K}$ production ($\approx$ 980 MeV) in HG. Based on these arguments, Rafelski and Müller [1, 2] have suggested that a large number of strange quarks present in QGP would automatically yield enhanced strange particle production in the HG resulting after hadronization of QGP.

It has been observed that a consistent and appropriate description of all the experimental results on the particle multiplicities and particle ratios at chemical freeze-out from the lowest SIS to the highest RHIC energies is described within the framework of a thermal statistical model as applied to a hot and dense HG phase. Recently we have given a model based on the geometrical excluded volume correction which describes suitably the thermodynamical quantities of a hot and dense HG [3].

Here we present strange/non-strange particle multiplicities and ratios [4] using our model [3] and compare them with the experimental data. We also show predictions for particle ratios employing other important models e.g., ideal HG model and Rischke model.

Formulations

This model assumes that the baryon of i^{th} species have an hard-core volume V_i. If $R = \sum_i n_i^{ex} V_i$ be the fraction of occupied volume, then the number density n_i^{ex} of i^{th} baryon can be written as :

$$n_i^{ex} = (1-R)\, I_i\, \lambda_i - I_i\, \lambda_i^2 \frac{\partial R}{\partial \lambda_i}, \qquad (1)$$

where λ_i is the fugacity of i^{th} baryons and I_i is the following expression containing the modified Bessel function of the second kind

$$I_i = \frac{g_i}{2\pi^2} \left(\frac{m_i}{T}\right)^2 T^3\, K_2(m_i/T) \qquad (2)$$

with g_i is the spin-isospin degeneracy factor. Eq. (1) can be rewritten in the form

$$R = (1-R) \sum_i n_i^0\, V_i - \sum_i n_i^0\, V_i\, \lambda_i \frac{\partial R}{\partial \lambda_i}, \quad (3)$$

with $n_i^0 \equiv I_i\, \lambda_i$. Taking $R^0 \equiv \sum_i X_i$, where $X_i \equiv I_i\, \lambda_i\, V_i$. If we put $\partial R/\partial \lambda_i = 0$, then

$$R \equiv \hat{R} = \frac{R^0}{1+R^0}. \qquad (4)$$

Above Eq. (4) gives the thermodynamically inconsistent value of R since first derivative in Eq. (3) is equated to be zero. This value of R exactly coincides with those obtained in thermodynamically inconsistent model [5]. Hence first derivative term in Eq. (3) is responsible for thermodynamical consistency. Thus by retaining the first order derivative term in Eq. (3), the thermodynamically consistent expression for R using Eq. (4) can be written as :

$$R = \hat{R} + \Omega\, R, \qquad (5)$$

with Ω is defined by

$$\Omega \equiv -\frac{1}{1+R^0} \sum_i I_i\, \lambda_i^2\, V_i \frac{\partial}{\partial \lambda_i}. \qquad (6)$$

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Following Neumann iteration method and retaining the terms upto second order the expression for R can be written as

$$R = \frac{\sum_i X_i}{1+\sum X_i} - \frac{\sum_i X_i^2}{(1+\sum_i X_i)^3} + \quad (7)$$
$$2\frac{\sum_i X_i^3}{(1+\sum_i X_i)^4} - 3\frac{\sum_i X_i\,\lambda_i \sum_i X_i^2\, I_i\, V_i}{(1+\sum_i X_i)^5}.$$

Finally by calculating the values of R and its first derivative $\partial R/\partial\lambda_i$, one can calculate the value of particle number density by using Eq. (1).

We have considered here a hot and dense hadron gas with baryonic and mesonic resonances having masses up to 2 GeV/c^2. In the above calculations we have considered that all the mesons behave as point-like particles. Furthermore, we have taken equal volume $V = 4\pi r^3/3$ for all baryons with a hard-core radius $r = 0.8$ fm.

TABLE I: (T, μ_B) values in MeV obtained by fitting the particle ratios using different models.

	Rischke model			Present model		
$\sqrt{s_{NN}}$ (GeV)	T	μ_B	δ^2	T	μ_B	δ^2
2.70	60.0	740.0	0.75	60.0	740.0	0.87
3.32	78.0	680.0	0.34	90.0	670.0	0.69
3.84	86.0	640.0	0.90	100.0	650.0	0.60
4.30	100.0	590.0	0.98	101.0	600.0	0.53
4.85	130.0	535.0	0.84	110.0	510.0	0.43
8.76	145.0	406.0	0.62	140.0	380.0	0.26
12.3	150.0	298.0	0.71	148.6	300.0	0.31
17.3	160.0	240.0	0.62	160.6	250.6	0.21
130.0	165.5	38.0	0.54	172.3	28.0	0.056
200.0	165.5	25.0	0.60	172.3	20.0	0.043

Results and Discussions

In Figure 1, we show the center-of-mass energy dependence of multiplicities of hadrons $\bar{\Lambda}$, $(\Omega+\bar{\Omega})$, Ξ^-, Λ, Φ, K^-, K^+ and π^+ as predicted by calculations in our present model. Curves A, B, C and D show the multiplicities of $\bar{\Lambda}$, $\Omega+\bar{\Omega}$, Ξ^- and Λ baryons scaled by factors of 0.02, 0.2, 0.1 and 0.02, respectively. Curves E, F, G and H depict the multiplicities of Φ, K^-, K^+ and π^+ mesons, respectively. We have also shown here experimental

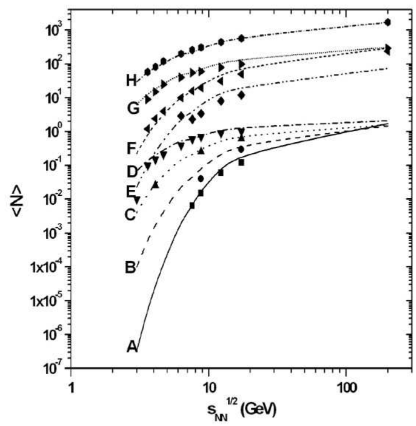

FIG. 1: Variations of multiplicities of $\bar{\Lambda}$, $(\Omega+\bar{\Omega})$, Ξ^-, Λ, Φ, K^-, K^+ and π^+ with respect to center-of-mass energy predicted by our present model. Experimental data measured in central Au+Au/Pb+Pb collisions have also been shown for comparison.

results measured in central Au+Au/Pb+Pb collisions for comparison. We found an excellent agreement between the theoretical predictions by our present thermal model and the experimental data for the total multiplicities of π^+, K^+, K^-, Λ, $\bar{\Lambda}$ etc. except for the case of $\Omega+\bar{\Omega}$, Ξ and Φ.

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