Strange Baryons and Antibaryons from Baryon-Poor QGP at RHIC

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We consider the abundance of strange baryons and find that at RHIC both baryon and antibaryon abundances will be dominated by the strange hyperon yields. Other related predictions are also discussed.

We have explored the consequences of high strangeness abundance we expect to be present in the baryon-poor quark-gluon plasma (QGP) environment formed *e.g.*, in the central rapidity region in Au–Au, maximum energy 100+100A GeV collisions at RHIC) [1]. About 10–20% of hadrons produced in these reactions will be strange, and since mesons dominate hadron abundance, there is qualitatively much more strangeness than baryon number, we find values 12–18 for the range of strange quark pairs per baryon. Thus strangeness yield per participant at RHIC is 20 times greater than seen at present at SPS energies, where we have 0.75 strange quark pairs per baryon [2]. During the break-up of the color charge deconfined QGP phase there is appreciable advantage for strangeness to stick to baryons given that the energy balance for the same flavor content favors production of strange baryons over kaons, $(E(\Lambda+\pi) < E(\mathrm{N{+}K}))$. When QGP is formed, we therefore expect and indeed find within our QGP evolution and hadronization model that hyperons dominate rapidity baryon distribution, *i.e.* most baryons and antibaryons observed at RHIC will be strange.

Does this prove QGP formation? We note that a similar argument could be made for reactions occurring purely in the confined phase, the main difference arises from the observation that the expected high abundance of strangeness per participating nucleon can be indeed produced in the deconfined QGP, as shown [1]. Making rather conservative assumptions we find not only that strangeness equilibrates, but indeed that at RHIC the rapid expansion/dilution effect causes an overpopulation of the strange quark phase space occupancy $\gamma_{\rm s}(T_f)$ at the time of chemical freeze-out. For a wide range of initial conditions we obtain a narrow band $1.18 > \gamma_{\rm s}(T_f) > 0.95$. We adopt the value $\gamma_{\rm s}(T_f) = 1.25$, also considering that gluon fragmentation add to both light and strange quark-pair phase space abundance.

We evaluated how this relatively large value of $\gamma_{\rm s}$, characteristic for the underlying QGP formation and evolution, impacts the strange baryon and anti-baryon observable emerging in hadronization. In the model calculations of strangeness production the time evolution in the plasma phase is followed up to the break-up of QGP. We recall that SPS-analysis showed that the system dependent baryon and antibaryon $m_\perp$-slopes of particle spectra are result of differences in collective flow in the deconfined QGP source at freeze-out [2]. There is a universality of physical properties of hadron chemical freeze-out between different SPS systems, and in our analysis a practical coincidence of the kinetic freeze-out conditions with the chemical freeze-out. We thus expect extrapolating the phase boundary curve to the small baryochemical potentials that the QGP break-up temperature $T_f^{\rm SPS} \simeq 145 \pm 5$ MeV will see just a minor upward change to the value $T_f^{\rm RHIC} \simeq 150 \pm 5$ MeV.

Thus we expect that major changes compared to SPS should occur only in the rapidity spectra of mesons, baryons and antibaryons; for the transverse expansion/hadronization we used the same approach that worked in the analysis of the SPS data [2]:
1) the QGP freeze-out/break-up occurs without a significant (transient) hadronic gas epoch;
2) the deconfined QGP state evaporates over a few fm/c, during which time it remains near to the freeze-out temperature, with energy lost due to particle evaporation and work done against the vacuum balanced by the internal energy flows.

This reaction picture can be falsified easily, since we expect, based and compared to the Pb–Pb 158A GeV results:
a) shape identity of RHIC $m_\perp$ and y spectra of antibaryons $\bar p$, $\overline{\Lambda}$, $\overline{\Xi}$, since in our approach there is no difference in their production mechanism, and the form of the spectra is determined in a similar way by the local temperature and flow velocity vector;
b) the $m_\perp$-slopes of these antibaryons should be very similar to the result we have from Pb–Pb 158A GeV since only a slight increase in the freeze-out temperature occurs, and no increase in collective transverse flow is expected.

The abundances of particles produced from QGP within this sudden freeze-out model are controlled by several further chemical parameters: the light quark fugacity $1 < \lambda_q < 1.1$, value is limited by the expected small ratio between baryons and mesons (baryon-poor plasma) when the energy per baryon is above 100 GeV, strangeness fugacity $\lambda_{\rm s} \simeq 1$ which value for locally neutral plasma assures that $\langle s - \bar s\rangle = 0$; the light quark phase space occupancy $\gamma_q \simeq 1.5$, overabundance value due to gluon fragmentation. Given these narrow ranges of chemical parameters and the freeze-out temperature $T_f = 150$ MeV, we compute the expected particle production at break-up. In general we cannot expect that the absolute numbers of particles we find are correct, as we have not modeled the important effect of flow in the laboratory frame of reference. However, ratios of hadrons subject to similar flow effects (compatible hadrons) can be independent of the detailed final state dynamics, as the results seen at SPS suggest [2], and we present such ratios below

The contribution from the fragmentation of gluons augments the light quark abundance and we consider the values $\gamma_q = 1.25, 1.5, 1.6$; we choose the value of baryochemical fugacity λ_q, see the header of table I, for which the energy per baryon (E/b) is similar to the collision condition (100 GeV), which leads here to the range $\lambda_q = 1.03 \pm 0.005$. We evaluate for these examples aside of E/b, the strangeness per baryon s/b and entropy per baryon S/b as shown in the top section of the table I. We do not enforce $\langle s - \bar{s}\rangle = 0$ exactly, since longitudinal flow can cause local (in y) non-conservation. However, since baryon asymmetry is small, strangeness is balanced to better than 2% in the parameter range considered. In the bottom portion of table I we present the compatible particle abundance ratios, computed according to the procedure developed in [2]. We have presented aside of the baryon and antibaryon relative yields also the relative kaon yield, which is also well determined within our approach.

The meaning of these results can be better appreciated when we assume in an example the central rapidity density of protons is $dp/dy|_{\rm central} = 25$. In table II we present the resulting (anti)baryon abundances. We see that the net baryon density $db/dy \simeq 15 \pm 2$, our example is consistent with baryon number transparency. We see that (anti)hyperons are indeed more abundant than non-strange (anti)baryons. When quoting results from table II do recall that:

1) we have chosen arbitrarily the overall normalization in table II, only particle ratios were computed, and

2) the rapidity baryon density relation to rapidity proton density is a consequence of the assumed value of λ_q, which we chose to get $E/b \simeq 100$ GeV per participant.

We firmly believe that our key result seen in table II, the hyperon-dominance of the baryon yields, does not depend on these hypothesis. Indeed, we have explored another set of parameters in our first and preliminary report on this matter [3], finding the same primary conclusion given the physics explained in the introduction. We note other interesting features of our results:

a) in table II the baryon rapidity density is at the level of 60% of the proton rapidity density;

b) in table I the entropy abundance per baryon implies a hadron abundance per baryon in range $h/b = [S/b]/4 = 125$–175. Thus the charged hadron abundance per baryon is in the range $[h^- + h^+]/b = 80$–120 – for each proton there are about 50-75 charged hadrons.

An amusing consequence of our finding is that an experiment like STAR where strange and non-strange baryons are distinguished, will observe about half as high proton rapidity density as compared to BRAHMS experiment which does not distinguish primary non-strange baryons from those originating in the hyperon decays and (mostly) accepted in this spectrometer.

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[1] J. Rafelski, and J. Letessier, "Expected Production of Strange Baryons and Antibaryons in Baryon-Poor QGP", *Phys. Lett.* B in press, nucl-th/9908024.

[2] J. Rafelski and J. Letessier, "Diagnosis of QGP with Strange Hadrons" *Acta Phys. Pol.* B (Dec. 1999) in press, hep-ph/9910300; "Hadrons from Pb–Pb collisions at 158*A* GeV", nucl-th/9903018; J. Letessier and J. Rafelski, *Phys. Rev.* **C 59** (1999) 947; *Acta Phys. Pol.*, **B 30** (1999) 153; *J. Phys.*, **G 25** (1999) 295.

[3] http://www.qm99.to.infn.it/program/qmprogram.html Presentation on Friday, May 24, 1999 at 11:25AM by J. Rafelski; to appear in proceedings of *Quark Matter 1999*, Torino, Italy within a group report "*Last call for* RHIC *predictions*". S. Bass *et. al.*, nucl-th/9907090.

TABLE I. For $\gamma_s = 1.25$, $\lambda_s = 1$ and γ_q, λ_q as shown: Top portion: strangeness per baryon s/B, energy per baryon E/B[GeV] and entropy per baryon S/B. Bottom portion: sample of hadron ratios expected at RHIC.

γ_q	1.25	1.5	1.5	1.5	1.60
λ_q	1.03	1.025	1.03	1.035	1.03
E/B[GeV]	117	133	111	95	110
s/B	18	16	13	12	12
S/B	630	698	583	501	571
$p/\bar{p}$	1.19	1.15	1.19	1.22	1.19
Λ/p	1.74	1.47	1.47	1.45	1.35
$\bar{\Lambda}/\bar{p}$	1.85	1.54	1.55	1.55	1.44
$\bar{\Lambda}/\Lambda$	0.89	0.91	0.89	0.87	0.89
Ξ^-/Λ	0.19	0.16	0.16	0.16	0.15
$\overline{\Xi^-}/\bar{\Lambda}$	0.20	0.17	0.17	0.17	0.16
$\overline{\Xi}/\Xi$	0.94	0.95	0.94	0.93	0.94
Ω/Ξ^-	0.147	0.123	0.122	0.122	0.115
$\overline{\Omega}/\overline{\Xi^-}$	0.156	0.130	0.130	0.131	0.122
$\overline{\Omega}/\Omega$	1	1.	1.	1.	1.
$\frac{\Omega+\overline{\Omega}}{\Xi^-+\overline{\Xi^-}}$	0.15	0.13	0.13	0.13	0.12
$\frac{\Xi^-+\overline{\Xi^-}}{\Lambda+\bar{\Lambda}}$	0.19	0.16	0.16	0.16	0.15
K^+/K^-	1.05	1.04	1.05	1.06	1.05

TABLE II. $dN/dy|_{\rm cent.}$ assuming in this example $dp/dy|_{\rm cent.} = 25$.

γ_q	λ_q	b	p	$\bar{p}$	Λ+Σ^0	$\overline{\Lambda}$+$\overline{\Sigma}^0$	$\Sigma^\pm$	$\overline{\Sigma}^\mp$	Ξ^0	$\overline{\Xi}^0$	Ω=$\overline{\Omega}$
1.25	1.03	17	25*	21	44	39	31	27	17	16	1.2
1.5	1.025	13	25*	22	36	33	26	23	13	11	0.7
1.5	1.03	16	25*	21	37	33	26	23	12	11	0.7
1.5	1.035	18	25*	21	36	32	26	22	11	10	0.7
1.60	1.03	15	25*	21	34	30	24	21	10	9.6	0.6