# Determination of the true $N_c$ limit of the baryons from the QCD phase diagrams

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## Introduction

The large number of colours ($N_c$) limit for the baryonic sector displays various inbuilt adversities. Our analysis evidently reveals the fact that $N_c$=3 is the true limit for the baryons. We have scrutinized two different appoaches for this very purpose and both exploit the Quantum Chromodynamics (QCD) phase diagram. A clear association can be developed between the 330 MeV mass quanta (which proposes to be the ultimate baryonic building block) [1,2] and the value of the quark chemical potential at the $N_c$=3 constraint. The correspondence between the 330 MeV mass quanta and the quark chemical potential is itself a very outstanding feature and gives a strong boost to both the authenticity of the $N_c$=3 limit for baryons and also itself serves as a substantiation for the existence of the 330 MeV mass quanta. The bag model equation of state of the strongly interacting matter is also in favour of this particular limit. . The correct value of critical temperature $T_c$ (matched to Lattice QCD simulation values) can be easily retrieved by applying $N_c$=3 limit to the parameters of the thermodynamical equation of state of strongly interacting matter

## Relation of the Quarkyonic phase and the 330MeV mass quanta under the Nc=3 limit

In this section, we will present evidence that validates the existence of the 330MeV mass quanta which proposes to be the ultimate building block for the baryons. This remarkable evidence is revealed through the study of the phase diagram of QCD in the large $N_c$ limit. The conventional phase diagram between temperature T and the quark chemical potential $\mu_q$ predicts a single transition for deconfinement and chiral symmetry restoration. However, recently Mc Lerran and Pisarski have brought forward a new phase diagram in the large $N_c$ limit [3], which approves the coexistence of the confined and the chirally restored symmetry phase called the quarkyonic phase. We are mainly interested in the boundary wall that separates quarkyonic phase from the confined hadronic phase. The generation of the boundary wall seems to be a valid theoretical approximation even if the large $N_c$ conjecture is invalid or has discrepancies.

The parameter which is of interest is the quark chemical potential $\mu_q$ and its value at the phase transition boundary is the target of our discussion. Quarkyonic matter appears when $\mu_q$=330 MeV. This value is the naive mass threshold for producing the Fermi sea of baryons, when temperature T=0. The boundary for chemical equilibration begins when the value of the quark chemical potential $\mu_q$ becomes equal to the constituent quark mass $m_q$.

The constituent quark mass is defined in a very natural manner for the phase diagram boundary condition. At T=0 the Fermi sea appears only when the baryon chemical potential exceeds the mass of the fermion and when talking in terms of the quark chemical potential, phase transition occurs when $\mu_q > m_q$. If M is the mass of the lightest baryon (that is the nucleon, M=990MeV), then quite obviously the constituent quark mass is

$$\mu_q = m_q = M/N_c = 330\text{MeV (for } N_c=3) \quad (1)$$

$$\mu q \to 1 \text{ (for } N_c \to \infty) \quad (2)$$

The constituent quark mass replaces the bare quark mass due to the fact that at T=0 in vacuum the quarks gear up with the gluons to form the constituent quarks that constitute the hadrons. The value of $\mu_q$ calculated for the phase diagram clearly coincides with the theoretical baryonic mass quanta proposed by Gregor [3,4] and a direct analogy becomes evident between the two very different approaches of calculating the constituent quark mass. The 330 MeV mass quanta proposed by Gregor is basically the constituent quark mass and can reproduce the entire baryonic spectrum. This coincidence between two varied different theoretical approaches is the basic background of this discussion. Since, these two values match each other, we can possibly comment that $N_c$=3 is the true limit for the baryonic sector.

## Estimation of $N_c$ from the bag model constant

In this section we will discuss as to how the bag constant is implicitly dependent upon the number of colours $N_c$ and its calculated theoretical value fits well when the number of colours are approximated to three. This analysis is performed with the help of the equation of state of the phase diagram. The MIT bag model equation of state is extensively used to scrutinize the properties of deconfined matter at large densities and high temperatures.

The confined segment of the phase diagram is the hadron gas. The hadron gas is treated as an ideal pion gas for the fact that the pressure of the hadronic phase at low temperature is dominated by the pressure of the lightest hadron. The phase transition between the hadronic gas and quark gluon plasma is governed by some set of parameters attaining certain specific values and the most important defining parameter in this category is the critical temperature $T_c$, which is of major significance in our analysis. This can be easily calculated from the other crucial parameters for the hadron gas.

For an ideal pion gas the Stefan- Boltzmann expressions eventually lead to equations for pressure and energy density. At the phase boundary between the hadronic and the QGP phase, when the chemical potential (μ) vanishes, that is $\mu_{QCD}=\mu_\pi=0$ then $T_{QGP}=T_\pi=T_c$ (here $\mu_{QCD,}$ $T_{QGP}$ and $\mu_{\pi,}$ $T_\pi$ are respectively the chemical potentials and temperatures of the deconfined and the confined phases) and then the pressure at the boundary wall would be equal. For the QGP state, the pressure parameter is directly related to the bag constant and Fig 1 displays the Variation pattern of one fourth power of pressure with temperature for both the pion gas and the QGP state.

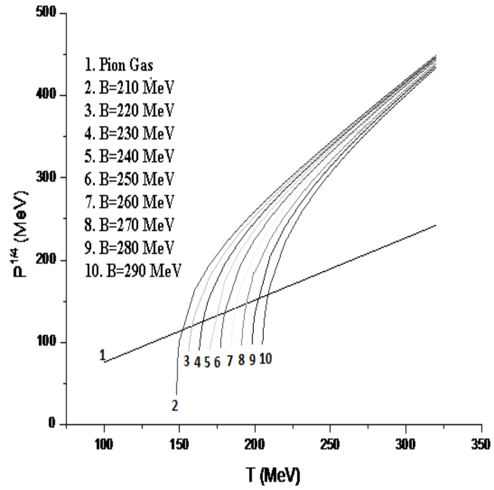


**Fig 1**: Variation pattern between $P^{1/4}$ with T for pion gas and the QGP state

The point where the variation lines for the QGP state intersects the straight line of the pion gas corresponds to the position of the critical temperature $T_c$. For different permitted values of the bag constant ($B^{1/4}$= 210MeV-290MeV), we obtain different values of the critical temperature $T_c$. Lattice QCD calculations numerically establish the existence of transition from the hadronic phase to a quark gluon phase in a temperature range between 150-200 MeV and the critical temperature range obtained from the figure accurately matches with these values. The observed range of critical temperature can be obtained only when $N_c$=3 and $N_f$ =2. This analysis gives us a clear insight that at least at the phase boundary $N_c$=3 is the true limit for the case of baryons.

## References


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