PROCEEDINGS OF SCIENCE

PoS(EPS-HEP 2009)455

# Hot and dense nuclear matter in an extended mean field approach

---

**Andrea Lavagno**[*]
*Dipartimento di Fisica, Politecnico di Torino and INFN, Sezione di Torino, Italy*
*E-mail:* `andrea.lavagno@polito.it`

We investigate the equation of state of hadronic and quark-gluon matter at finite temperature and baryon density considering the possible formation of mixed phase in high energy heavy ion collisions. The analysis is performed by requiring the Gibbs conditions on the global conservation of baryon number, electric charge and strangeness number. For hadronic phase, we study an extended relativistic mean-field theoretical model with the inclusion of $\Delta$-isobar, hyperons and lightest pseudoscalar and vector mesons degrees of freedom. For the quark sector, we employ a MIT-Bag model with a Bag "constant" depending on the baryon chemical potential. In this context, the behavior of strangeness densities and strangeness-antistrangeness separation in the hadron-quark-gluon mixed phase are analyzed.

*European Physical Society Europhysics Conference on High Energy Physics, EPS-HEP 2009,*
*July 16 - 22 2009*
*Krakow, Poland*

---

[*] Speaker.

The relativistic mean-field (RMF) model, first introduced by Walecka and Boguta-Bodmer in the mid-1970s, is widely successful used for describing the properties of finite nuclei as well as hot and dense nuclear matter. In this context, the total baryon Lagrangian density can be written as

$$\mathscr{L}_B = \mathscr{L}_{\rm octet} + \mathscr{L}_\Delta \,, \tag{1}$$

where $\mathscr{L}_{\rm octet}$ stands for the full octet of baryons ($p$, $n$, $\Lambda$, $\Sigma^+$, $\Sigma^0$, $\Sigma^-$, $\Xi^0$, $\Xi^-$) (see, for example, Ref.s[1, 2] for details), $\mathscr{L}_\Delta$ corresponds to the degree of freedom for the $\Delta$ isobars ($\Delta^{++}$, $\Delta^+$, $\Delta^0$, $\Delta^-$) [3].

Because of we are going to describe finite temperature and density nuclear matter with respect to strong interaction, we have to require the conservation of three "charges": baryon number, electric charge and strangeness number described by: $\mu_B$, $\mu_C$ and $\mu_S$, respectively, the baryon, the electric and the strange chemical potentials of the system. Therefore, the chemical potential of particle of index $i$ can be written as

$$\mu_i = b_i\,\mu_B + c_i\,\mu_C + s_i\,\mu_S \,, \tag{2}$$

where $b_i$, $c_i$ and $s_i$ are, respectively, the baryon, the electric charge and the strangeness quantum numbers of the $i$-th hadronic species. All the thermodynamical quantities can be obtained from the baryon grand potential $\Omega_B$ in the standard way [4].

At low baryon density and high temperature, the contribution of the lightest pseudoscalar and vector mesons to the total thermodynamical potential becomes very relevant. From a phenomenological point of view, we can take into account of these contributions by incorporating such mesons by adding to the thermodynamical potential their one-body contribution, i.e. the contribution of an ideal Bose gas with an effective chemical potential [5].

In this investigation we use a simple MIT bag model to describe the quark phase. It is well known that, using the simplest version of the MIT bag model, at moderate temperatures the deconfinement transition takes place at very large densities if the bag pressure $B$ is fixed to reproduce the critical temperature computed in lattice QCD. On the other hand there are strong theoretical indications that at moderate and large densities (and not too large temperatures) diquark condensates can form, whose effect can be approximately taken into account by reducing the value of the effective bag constant. A phenomenological approach can therefore be based on bag constant depending on the baryon chemical potential, as proposed in Ref. [6].

The main goal of this contribution is to investigate the hadron-quark-gluon phase transition at finite temperature and baryon chemical potential. To describe the mixed phase we use the Gibbs formalism applied to systems where more than one conserved charge is present. The structure of the mixed phase is obtained by imposing the Gibbs conditions for chemical potentials ($\mu_B^{(H)} = \mu_B^{(Q)}$, $\mu_C^{(H)} = \mu_C^{(Q)}$, $\mu_S^{(H)} = \mu_S^{(Q)}$) and pressure ($P^H = P^Q$) and by requiring the global conservation of the total baryon (B), electric charge (C) and strange (S) densities in hadronic (H) phase and in quark (Q) phase:

$$\begin{aligned}
&P^{(H)}(T,\mu_B,\mu_C,\mu_S) = P^{(Q)}(T,\mu_B,\mu_C,\mu_S)\,,\\
&\rho_B = (1-\chi)\rho_B^H + \chi\rho_B^Q\,,\\
&\rho_C = (1-\chi)\rho_C^H + \chi\rho_C^Q\,,\\
&\rho_S = (1-\chi)\rho_S^H + \chi\rho_S^Q\,,
\end{aligned} \tag{3}$$

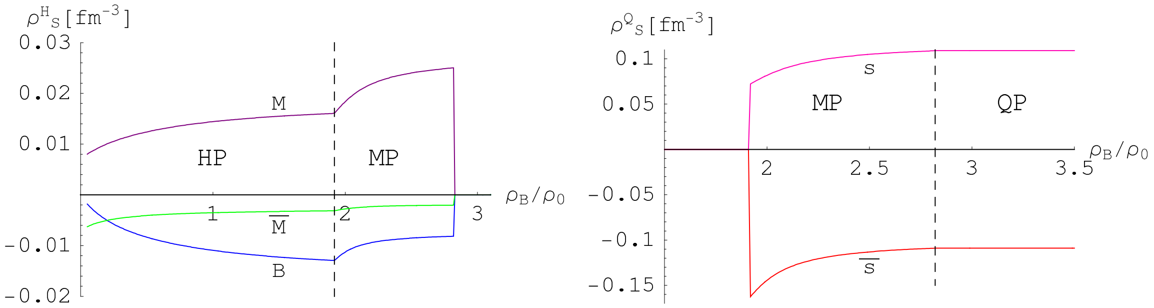

**Figure 1:** *Left panel:* Strangeness densities of baryons ($B$), mesons ($M$) and anti-mesons ($\overline{M}$) in the pure hadronic phase (HP) and in the mixed phase region (MP). *Right panel:* Densities of strange quarks ($s$ and $\bar{s}$) in the mixed phase (MP) and in the pure quark-gluon phase (QP). In both panels the temperature is $T$=120 MeV.

where $\chi$ is the fraction of quark-gluon matter in the mixed phase. In this way we can find out the phase coexistence region in the $(T, \mu_B, \mu_C, \mu_S)$ space. At fixed $T$ and $\mu_B$, the charge $\mu_C$ and strangeness $\mu_S$ chemical potentials are obtained by fixing the total electric charge $Z/A$ (for example, $Z/A = 0.401$ for lead-lead heavy ion collisions) and the total strangeness neutrality by the conditions

$$\rho_C = \frac{Z}{A}\rho_B\,, \quad \rho_S = 0\,. \tag{4}$$

At this point we are able to compute all the interesting physical quantities such as the dependence of the pressure and energy density, the fraction of produced particles at different values of temperature and baryon densities (or baryon chemical potentials). Among the several topics of investigation, let us drive the attention to the strangeness production in different phases of nuclear matter. In Fig.[1] we report, at fixed temperature $T$=120 MeV, both the strangeness densities of hadrons and quarks in the mixed phase region in comparison with the pure hadron phase and pure quark phase. It is relevant to note a remarkable increasing of the strange baryon-meson and strange quark densities at the beginning of the mixed phase. This aspect could be very relevant in the phenomenological interpretation of the relativistic heavy ion collisions data.

## References

[1] N.K. Glendenning, S.A. Moszkowski, Phys. Rev. Lett. **67** (1991) 2414.

[2] J. Schaffner-Bielich, A. Gal, Phys. Rev. C **62** (2000) 034311.

[3] S. Li, G. Mao, Y. Zhou, W. Greiner, Phys. Rev. C **56** (1997) 1570.

[4] M. Di Toro, A. Drago, T. Gaitanos, V. Greco, A. Lavagno, Nucl. Phys. A **775** (2006) 102.

[5] H. Müller, Nucl. Phys. A **618** (1997) 349.

[6] L. Bonanno, A. Drago, A. Lavagno, Phys. Rev. Lett. **99** (2007) 242301.