A quasiparticle description of the equation of state in SU(3) lattice QCD

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The lattice QCD calculations suggest the appearance of a phase transition between the quark gluon dominated high temperature state and the hadronic state in the low temperature region, characterized by a large difference in the number of degrees of freedom. At temperatures much greater than the critical temperature, the weak coupling, allows the use of perturbative methods. Near the critical temperature strong nonperturbative effects dominate the deconfined state. Several models have been proposed to understand this phenomenon by assuming the appearance of massive quasiparticles, namely massive quarks and gluons. Such a quasiparticle picture has also been invoked in solid state physics and other fields to study phase transitions in which a large part of the interaction can be included into the effective masses of particles which move freely. In this work, we analyze recent lattice QCD results using a phenomenological equation of state with light quarks and massive gluons. Such a model would be a preferable starting point for phenomenological hadronization models and for a description of the strongly interacting matter near the phase transition.

Early lattice data on the pressure and energy density of pure SU(3) gauge theory (without dynamical quarks) were interpreted with a constant gluon mass, $M_g = 500$ MeV, and a constant bag constant $B^1/4 \simeq 200$ MeV [1]. Recent SU(3) lattice data were interpreted with an equation of state where both the gluon mass and bag parameter were temperature dependent [2]. The lattice calculations which include dynamical quarks based on Wilson fermion formulations appeared recently, for $N_f = 2$, and $N_f = 4$. Here $N_f$ is the number of flavours. This data has been used for the extraction of an equation of state for the QGP containing massive gluons and quarks [3]. Here, the masses and the bag parameter obtained were temperature dependent.

The lattice data for $N_f = 2$ and $N_f = 3$ based on staggered fermion formulations have also appeared [4], which we analyze using following equation of state. The pressure in the case of a noninteracting gas of massive gluons
and quarks can be written as

\[ p_q = \left( \frac{21N_f}{2} f(m_q/T) + 16 h(m_g/T) \right) \frac{\pi^2}{90} T^4 - B, \]  

(1)

where \( m_q \) and \( m_g \) are the masses of quark and gluon, respectively and \( B \) is the bag constant. The functions \( f(m_q/T) \) and \( h(m_g/T) \) are given by

\[
\begin{align*}
  f(m_q/T) &= \frac{360}{7\pi^4} \int_0^\infty du \ u^2 \ln \left( 1 + e^{-\sqrt{u^2 + (m_q/T)^2}} \right), \\
  h(m_g/T) &= -\frac{45}{\pi^4} \int_0^\infty du \ u^2 \ln \left( 1 - e^{-\sqrt{u^2 + (m_g/T)^2}} \right)
\end{align*}
\]

(2)

The figure shows the lattice data [4] for pressure in the case of 2 and 3 flavour QGP along with a pure gluon plasma. The solid lines are the fit obtained with Eq. (1). The fit parameters are given in the table. A constant gluon mass and bag constant suffice to give a very good fit within the errors bars (15 %) of the data. In principle the quark mass should also be made as a parameter, for which the calculations are under way. The QGP produced at RHIC energies is expected to be of three flavour. Such a simple equation of state presented here can be very important for hydrodynamical calculations in the contexts of RHIC data.

<table>
<thead>
<tr>
<th>( N_f )</th>
<th>( m_q ) (GeV)</th>
<th>( B^{1/4} ) (GeV)</th>
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<tr>
<td>0</td>
<td>0.7</td>
<td>0.204</td>
</tr>
<tr>
<td>2</td>
<td>1.1</td>
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</tr>
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