A Thermodynamically Congruous Approach for QGP Equation of State in the Early Universe

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Introduction

The strong force is ably described by Quantum Chromo-Dynamics (QCD), which also foretell us about a phase shift from a confined, hadronic to a hot, deconfined Quark-Gluon Plasma (QGP) medium at very high temperatures [1]. An Equation of State (EoS) is used to investigate the uncanny characteristics of this state of matter by knowing the variations of different thermodynamic quantities. For this, we use Friedmann equations computed from the Einstein field equations via the FLRW (Friedmann-Lemaitre-Robertson-Walker) metric in order to calculate the EoS.

EoS of QGP from a thermodynamically congruous approach

In massive ion collisions or the extreme states where QGP is created, there exists very large temperatures and density values. Quasi-particles are generated - which are the thermal excitations- due to the interplay between the existing particles (quarks and gluons) at these extreme conditions which results in their masses to be highly dependent on the temperature. Our phenomenological model used as the effective mass of the quasi-particles that is extracted with the help of thermal quark mass [2]. These effective masses are used to determine the evolution of our primordial universe under thermodynamically congruous approach. In this study, we used free energy for quarks and gluons [3]. It is expressed as:

$$F_i = \pm T g_i \int dk \rho_i(\kappa) \ln(1 \mp e^{-\sqrt{[(m_{eff})^2+\kappa^2]}/T}) \quad (1)$$

Where, $\rho_i(k)$ is the density of state of quarks and gluons while g_i is the factor of degeneracy for the quasi-particles. The 'i' index denotes the equation for quarks as well gluons with the positive sign for the bosons and the negative sign for the fermions. The important term as the interface free energy is used to separate the two medium from hadrons state to quarks state [3]. Finally, the total free energy is able to describe the physical picture of exotic system.

Now, we use effective quark masss as m_{eff} which denotes the quasi-particle effective mass taken as a linear function of the current quark mass (m_{cq}) and the temperature dependent quark mass (m_T) term along with the paired term of both the masses, i.e., ($m_{cq}m_T$) given by [4, 5]:

$$m_{eff}^2 = m_{cq}^2 + m_T^2 + \sqrt{2} m_{cq} m_T \quad (2)$$

The thermal mass (m_T) exhibits a strong dependence on the coupling parameters and the temperature and it is defined in Ref. [4, 5].

With the help of our model, we can now use the Friedmann equations to compute the fluctuations in the total pressure (P) and energy density (ε) as a function of time given as [6, 7]:

$$\frac{d\varepsilon}{\sqrt{3\varepsilon}(\varepsilon + P)} = -2\sqrt{2\pi G} dt \quad (3)$$

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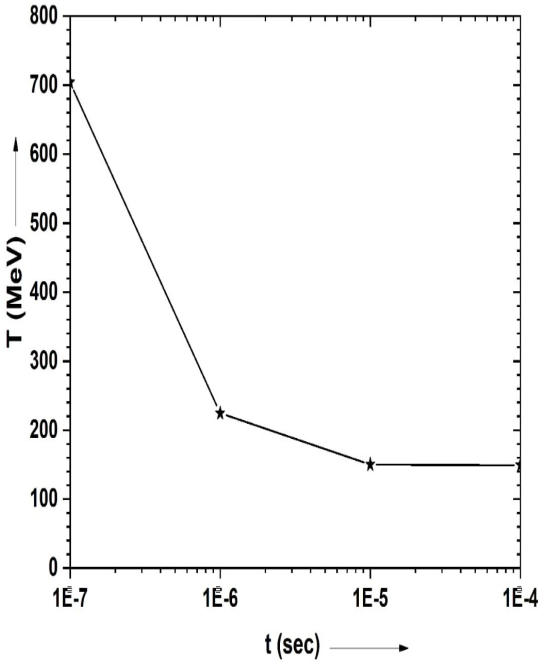

FIG. 1: Evolution of temperature (T) as a function of time (t).

Now, the equation for energy density (ε) can be computed as:

$$\varepsilon = -P + T\frac{dP}{dT} \tag{4}$$

Using energy density (ε) and pressure term (P), we are able to show the temperature variation with respect to time. Therefore, the time evolution of temperature can be computed easily and it is expression as [6, 7]:

$$\frac{dT}{dt} = \frac{d\varepsilon}{dt} \times \left(\frac{d\varepsilon}{dT}\right)^{-1} \tag{5}$$

Results and Conclusion

A temperature of transition for the phase shift between QGP and hadronic state can be found in the lattice gauge theory of QCD [8], taking place at values roughly around 150 MeV. We present a plot between the temperature and time which can be analysed to predict the transition temperature for such phase shift. Figure 1 shows the variation of T with t, where a transition can be predicted from the fact of temperature being constant in the region between $10^{-4} - 10^{-5}s$, at which a temperature value observed around $T \approx 150MeV$. From [9], it is seen that when the dynamical quark masses are used in contrast with the phenomenological models, they yield an order one and a smooth crossover phase shift for the former and the later one. To look into the phase transitions, we didn't find very much clear picture although our results are in well conformity with the results produced by Sanches et al [6, 7]. The work is still in progess in this direction.

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