Early Universe Expansion of QGP in the Presence of Finite Chemical Potential

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Introduction

During the early moments of the universe, it is hypothesized that matter existed in the form of a Quark-Gluon Plasma (QGP). To comprehend the QGP's temporal progression, it's crucial to account for the influence of a finite chemical potential [1]. The current work is devoted to calculate the time evolution of temperature (T), we endeavor to solve the time evolution (t) equation, derived from the Friedmann equation [2]. Incorporating the effects of the chemical potential is vital for gaining a deeper understanding of the equation of state of QGP during the early universe.

Model Description

In our approach, we utilize a simple quasi-particle model that takes into consideration the influence of temperature and chemical potential on quark mass using [3, 4]:

$$m^2_{j=q}(T,\mu) = \gamma_q(g^2(p))[T^2 + \frac{\mu^2}{\pi^2}] \tag{1}$$

In this equation, γ_q and $g(p)$ are are defining parameters related to QGP flow and the running coupling constant of QCD, respectively. p and μ represent the momentum and chemical potential terms. The free energy of quarks and gluons can be elucidated through the subsequent equation [4, 5]:

$$F_j = \mp T g_j \int \rho_j(p) \ln(1 \pm e^{\frac{-\sqrt{(m_j)^2+p^2}}{T} + \frac{\mu}{T}})dp \tag{2}$$

Here, $\rho_j(p)$ denotes the state density for quarks and gluons, while other variables maintain their conventional meanings [4, 5]. Additionally, we use the interface term, separating the hadronic and QGP phases [4, 5]:

$$F_{int} = \frac{1}{4}\gamma r^2 T^3 \tag{3}$$

In this equation, r represents the QGP droplet radius, and γ is the effective RMS value of the quark and gluon flow parameter.

The total pressure is the sum of individual pressure terms contributed by the total free energy term defined in Ref. [6]. Then the energy density time evolution equation from the Friedmann equations can be computed using Ref. [7] and defined as:

$$\frac{d\epsilon}{dt} = -\sqrt{\frac{8\pi G}{3}}(3\sqrt{\varepsilon}(\varepsilon + P)) \tag{4}$$

The pressure can easily be obtained [6]. Finally, we can solve the time evolution of temperature as [7]:

$$\frac{dT}{dt} = \frac{d\epsilon}{dt} \times \frac{1}{(\frac{d\epsilon}{dT})} \tag{5}$$

Solving $T(t)$, it provides the equation of state (EOS) of QGP, considering the effects of finite

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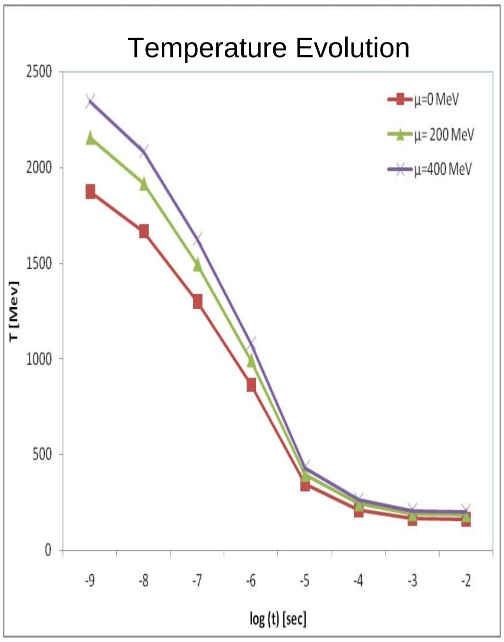

FIG. 1: Temperature with respect time is shown with chemical potential.

chemical potential on the early universe's time evolution.

Results

In this study, we have successfully derived the expressions for $T(t)$ and determine the time evolution of temperature. Our motivation stems from the work of Sanches et al. [7] and Kumar [8], determined the equation of state for the early universe in the absence of a chemical potential. In our prior work [8], we demonstrated how energy density and temperature vary with time at zero chemical potential. In this work, we plot time evolution of temperature using chemical potential. For all values of the chemical potential, the temperature rapidly decreases until 10^{-5} seconds, after which it stabilizes. This behavior suggests a transition temperature around 150 MeV. As we increase the chemical potential, the temperature also rises, which provides a promising signal for studying phase transitions. This work is valuable in the fields of early universe cosmology and astrophysics.

Conclusions

This study is expected to provide crucial insights into the evolution of our universe and the characteristics of QGP under finite chemical potential conditions. It is essential to consider the forecasts of theoretical models, enabling both theoreticians and experimentalists to verify these predictions through probing techniques such as heavy-ion collisions. The pursuit of understanding this enigmatic state of matter continues tirelessly, yet our knowledge of this phase remains limited. Moreover, it is vital to recognize the importance of these investigations in the context of cosmology and astrophysics. A deeper comprehension of QGP and its evolution enhances our understanding of the universe's initial conditions, further validating prevailing models such as the Big Bang theory, which elucidates the origin of our universe. Overall, the present study aids us in investigating the characteristics of the early universe's quark-gluon plasma (QGP) in the presence of a finite chemical potential.

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