



# Early Universe Expansion of Quark Gluon Plasma with Quasi-Particle Approach

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## Abstract

We study the expansion of early universe using quasi-particle approach. In order to determine the accurate time evolution of the thermodynamic parameters in the early universe of quark gluon plasma (QGP), we solve the Friedmann equation. The calculation results provide us the time variation of the energy density and also the time evolution of temperature in the early universe using finite quark mass value. The results shown in figures show the time evolution of early universe which also help to calculate other thermodynamic observables.

## Introduction

The ongoing experiment provide us the best opportunity to study the properties of matter in the early universe [1, 2].

## Model Description

To determine the precise time evolution of the thermodynamic parameters in the early Universe, we solve the Friedmann equation [3] that, assuming that the expansion of the Universe is isentropic, takes the form:

$$\frac{d\varepsilon}{dt} = -3\sqrt{\frac{8\pi G\varepsilon}{3}}(\varepsilon + P). \quad (1)$$

The above equation helps to find the temporal evolution of the energy density for any given equation of the state  $p(\varepsilon)$  [3, 4].

## QGP equation of state

The free energy,  $F_i$  for quarks using finite quark mass is given Ref. [5, 6]. It is defined as:

$$F_i = \mp T g_i \int dk \rho_i(k) \ln(1 \pm e^{-\sqrt{m_i^2 + k^2}/T}), \quad (2)$$

where  $\rho_i(k)$  is the density of states of the particular particle  $i$  (quarks and gluons), and  $g_i$  is the degeneracy factor [7]. Using equation (2), we can calculate pressure and energy density using thermodynamic relation. It is given as Ref. [7]:

$$P_i = -\frac{d}{dv} F_i. \quad (3)$$

The total pressure is the sum of the pressure due to all the constituents. Further the energy density is calculated as [7],

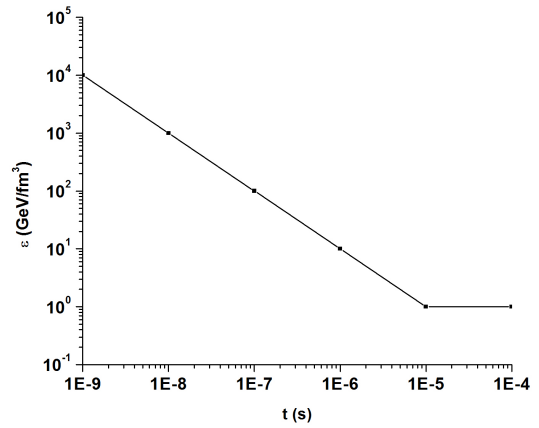
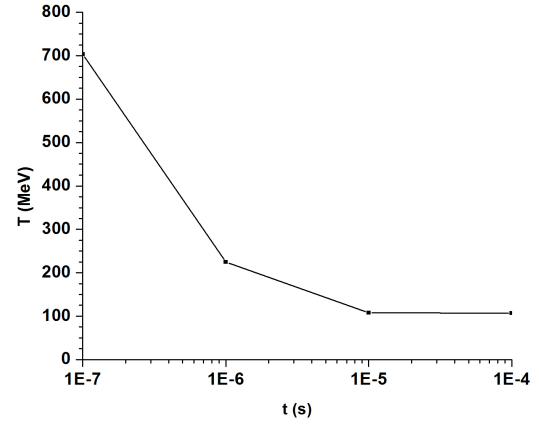
$$\varepsilon = T \frac{d}{dT} P - P. \quad (4)$$

Using these relations, we show the time evolution of temperature and energy density. Since the equation of state are different, fixing the initial energy density implies that the evolution starts at different initial temperatures for different model [3, 4]. So, we use the relation as :

$$\frac{dT}{dt} = \frac{1}{\left(\frac{d\varepsilon}{dT}\right)} \times \frac{d\varepsilon}{dt}. \quad (5)$$

We solve it for  $T(t)$ . These relations are useful to study the quark gluon plasma equation of state.

(Figure): The variation of temperature and energy density as a function of time is shown.



## Results and Conclusion

In Figures [1] we show the plots of temperature as a function of time and energy density as a function of time. The figures show that in the interval from  $10^{-5}$  to  $10^{-4}$  sec, we expect to be sensitive to the phase transition. We also pointed out that the critical temperature occurs around 150 MeV. Results are compared with the Sanches et al [3, 4]. Overall our results are significant in studying the QGP equation of state. The future experimental facilities are interesting to identify observable effects of the QGP phase in the primordial Universe after big bang.

## References

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