Quantum chromodynamics (QCD), the fundamental theory of strong interactions, predicts a phase transition from confined phase of hadronic state to deconfined phase of free quark and gluon, the so called quark-gluon plasma. The evolution of such deconfined state due to the central collisions of two massive nuclei has been a subject matter of present day of ultra-relativistic heavy-ion collision. Presumably the early universe was in this state up to about 10µs after the big-bang. Today the core program of ultra-relativistic nucleus-nucleus collision is to study the properties of the strongly interacting matter at very high energy density and temperature so that it can create this deconfined state of matter in heavy-ion collision experiments. So the experimental measurement and theoretical investigation of electromagnetic observables in heavy-ion collision constitutes one of the most promising and exciting fields in high energy physics. This promising and exciting observables indicate nothing but the emission of high energy photons and leptons and these particles have a large mean free path due to the small cross section for electromagnetic interaction in the plasma. These particles carry the whole informations about the existence of the plasma and it is moreover true that over a large range of expected plasma temperature, its radiation can be observed throughout its evolution. So they are considered to be the good signature for the formation of QGP.

So far, many authors have studied the production of photon in a QGP at finite temperature and this temperature is related to the energy density $\epsilon$ given by the stefan boltzmann $\epsilon \sim T^4$ and the thermodynamic relation for this system is given as: $\frac{dp}{dT} - p = \epsilon$; $p = \frac{1}{3}\sigma T^4 - AT$ and the term linear in $T$ gives the non-perturbative effect in calculating the pressure and $A$ is the constant value. Recently T.S.Biro et al. derived the rate equation describing the chemical equilibrium of quarks and gluons and subsequently by D.Dutta et al. They calculate this type of ideal fluid dynamics to study the subsequent evolution of kinetically equilibrated QGP phase at high energy and temperature. Moreover experimental observations from Pb – Pb collision at $\sqrt{s} = 158$ A GeV at CERN SPS indicate favourable interest in this electromagnetic probes and the observations show that the transverse momentum distribution function of direct photon is a significant in the photon induced reaction at the same $\sqrt{s}$ for the transverse momentum greater than 1.5 GeV/c in the central collision but there is doubt about the QGP formation in the central region at SPS energies. This suggests direct photon production as a signal of the QGP phase. Moreover one important thing is that direct photon production is whether dependent on the space time evolution scenarios of the finite QGP lifetime. For this we focus the photon radiation directly from the thermalized quark-gluon plasma at $T = 0.25$ GeV which expands and cools, comes back to hadronic matter with the production of latent heat which again heats and cools and eventually at last freezes out into hadrons, mostly as pions. In this paper, the photon radiation at transition phase around the temperature $T = (0.15 - 0.17)$ GeV too, have been calculated and compared with the hot phase of QGP system i.e the temperature $T = 0.25$ GeV with the quark mass depending on the interacting coupling parameter. Many investigations so far have been studied to see hard real photon production from the Quark- Gluon Plasma. Based on this results we focus our photon production rate at the thermal equilibrium, by using QCD annihilation and compton process between quark, antiquark and gluon by using different distribution functions for quark, antiquark and gluon. They have been discussed in this paper as different cases for different values of temperature $T$ with different coupling parameter used in QGP fireball formation. The coupling parameter is calculated.

ELECTROMAGNETIC RADIATION FROM AN EQUILIBRIUM QUARK-GLUON PLASMA SYSTEM

S.S.Singh¹ and Agam K. Jha

Department of Physics and Astro-Physics, University of Delhi, Delhi - 110007, INDIA

We study the electromagnetic radiation from a hot and slightly strong interacting fireball system of quark-gluon plasma using the Boltzmann distribution function for the incoming particles and Bose-Einstein distribution for gluon in first calculation of electromagnetic radiation and Fermi-Dirac distribution for quark, antiquark and Boltzmann distribution for gluon in our second calculation. The thermal photon emission rate is found that it is infrared divergent for massless quarks which are discussed by many authors and regulate this divergence using different cut-off in the quark mass. However we remove this divergence using the same technique of Braaten and Pisarski in the thermal mass of the system by using our model calculation in the coupling parameter. Thus the production rate of the thermal photon is found to be smoothly worked by this cut off technique of our model. The result is found to be matched with the most of the theoretical calculations and it is in the conformity with the experimental results of 200 A GeV S + Au collision of LHC.

*Electronic address: sssingh@physics.du.ac.in, akjha@physics.du.ac.in.
with this parametrised factor $\gamma_{q,g}[10]$, where $\gamma_q = \alpha_s\gamma_q$ and ‘a’ is either 6 or 8 with $\gamma_q = 1/6$.

**Photon production from QGP:** The calculation of photon production from a QGP is found to be very interesting theoretical problem. In the early stage of universe, it was a very little understood about photon production just before the thermalisation process of the system. So we consider the thermalised state of QGP after big-bang as the system takes a longer time compared to the time scale associated with the photon production. Moreover it is stated that for the coupling parameter $\alpha_s << 1$, the result turns out to be slow expansion near the equilibrium temperature, even it is not justified condition. So resulting by this, there are a good number of research works in photon production from the quark-gluon plasma considering the quark, antiquark annihilation process as well as compton process. Most of the time in which photon radiation is used by Boltzmann distribution function by many authors for incoming particles quark and antiquark and for gluon as Bose-Ein. distribution function. Thus, now we consider the same approach in which the incoming particles, quark and antiquark are having the Boltzmann distribution function $f_q(E_q) = \exp(-E/T)$ and the gluon as Bose-Ein. distribution function $f_g(E_g) = \frac{1}{\exp(E/T)+1}$ in our first calculation and we calculate the photon emission rate produced or photon distribution spectrum with QCD coupling parameter $\bar{\alpha_s}$ as follows:

$$
E \frac{dN^{ann}}{dP_d} = \frac{5\alpha_s\bar{\alpha}_s}{2\pi^2} T^2 \exp(-E/T)[\ln\left(T/m_q\right) - C_F],
$$

where $C_F = C_{\text{Euler}} + 1 + \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{\ln(n)}{n^2}$, $C_{\text{Euler}}$ is the Euler number 0.577215 and $\bar{\alpha}_s = 1/137$.

The expression above shows the computed thermal spectrum. Because of the quark masses set to be zero, the expression is replaced by infrared cut-off $2k_F^2$ in the quark mass. The infrared divergence is obtained and it is regulated by the technique given by Braaten and Pisarski [9], and this is set as $k_F^2 = \frac{\Lambda^2}{2\pi^2}$ where 'g' is QCD coupling constant and it is determined from the model where QGP fireball is formed [10]. The magnitude of $g^2$ is given:

$$
g^2 = \frac{16\pi}{27} \frac{1}{\ln(1 + \frac{m_q^2}{\Lambda^2})}
$$

with the QCD parameter $\Lambda = 0.15$ GeV and $k = (\frac{\Lambda^2}{2\pi^2})^{\frac{1}{2}}$ for minimum value of $g$ with $N = \frac{16\pi}{27}$ where $\gamma_{q,g}$ is the phenomenological flow parameter [10] defined above to take care of the hydrodynamical aspects of the hot QGP droplets. It is obviously found that g is approximately equal to 1.29 which is slightly strong compared to the other calculations and $\alpha_s = \frac{g^2}{4\pi}$. The result produced using this modification is shown in the Fig.3 for the different values of $T$. Again we calculate the compton process i.e $q(q)g \rightarrow \gamma(q)$ using the same distribution function for quark and gluon. But the distribution function for quark and antiquark are same for Boltzmann and Bose-Ein. distribution and the photon production rate obtained by this process is given by the following relation:

$$
E \frac{dN^{comp}}{dP_d} = \frac{5\alpha_s\bar{\alpha}_s}{2\pi^2} T^2 \exp(-E/T)[\ln(\frac{4ET}{m_g^2}) - C_E],
$$

where $C_E = C_{\text{Euler}} + \frac{1}{2}$. In a similar way we plot the figure for this process and found to be similar for both annihilation and compton process for the same distribution function. In annihilation process, the logarithmic value of $E \frac{dN^{ann}}{dP_d}$ is slightly higher than the compton process. But there is no much difference for higher value of $P_T$ results.

In this second calculation we again use the distribution function of quark as Fermi-Dirac $f_q(E_q) = \exp(-E/T)$, and Boltzmann distribution for gluon as $f_g(E_g) = \exp(-E/T)$. As we did in the first case, we do the same production rate for annihilation as well as compton process for the different value of $T$ with QCD coupling parameter. The production rate for annihilation process is given as:

$$
E \frac{dN^{ann}}{dP_d} = \frac{10\alpha_s\bar{\alpha}_s}{9\pi^4} T^2 \exp(-E/T)[\ln(\frac{4ET}{m_q^2}) - C_{F1}],
$$

where $C_{F1} = C_{\text{Euler}} + 1$ and the compton process as:

$$
E \frac{dN^{comp}}{dP_d} = \frac{5\alpha_s\bar{\alpha}_s}{2\pi^2} T^2 \exp(-E/T)[\ln(\frac{4ET}{m_q^2}) - C_E],
$$

where $C_E = C_{\text{Euler}} + \frac{1}{2} + \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{\ln(n)}{n^2}$. In both process of annihilation as well as compton, the distribution function used for quark and antiquark are same as the system is in thermal equilibrium. The results for this annihilation and compton process are again shown in the Fig. 3 and 4.

**Results and Conclusions:** In this present paper, we attempt to evaluate the photon production rate through two processes using the Boltzmann distribution function and Fermi-Dirac distribution function for the incoming particles quark and antiquark for hot QGP system as well as just around transition phase region for different coupling parameters based on $\gamma_q = 6\gamma_0$ and $\gamma_g = 8\gamma_0$. The photon production rate for both of these parameters are found to be almost similar in both the distribution functions. So the effect of these parameters contribute less in finding the photon distribution spectrum. But the free energy of the QGP at temperature $T = 0.17$ GeV is found to be dependent on this different value of coupling constants for both the cases. The difference $\gamma_{g, s}$
FIG 1: The free energy $F$ (MeV) of QGP, at thermal temperature $T = 0.17$ GeV at different $\gamma_{q,g}$ with bubble size $R$ in Fermi.

FIG 2: The free energy $F$ (MeV) of QGP, at thermal temperature $T = 0.25$ GeV at different $\gamma_{q,g}$ with bubble size $R$ in Fermi.

FIG 3: The photon emission rate through ann, $Y = \frac{E_{\gamma}}{gramm}$, log($Y$) at thermal temperature $T = 0.25$ GeV, 0.17 GeV and 0.15 GeV at different $\gamma_{q,g}$ through Boltz dist. for $q$ and $\bar{q}$.

FIG 4: The photon emission rate through comp, $Y = \frac{E_{\gamma}}{comp}$, log($Y$) at thermal temperature $T = 0.25$ GeV, 0.17 GeV and 0.15 GeV at different $\gamma_{q,g}$ through Boltz.dist.for $q$ and $\bar{q}$.

The free energy for $\gamma_g = 8\gamma_q$ is slightly less for increase in bubble size compared with the $\gamma_g = 6\gamma_q$, but for the smaller bubble, free energy is the same. At temperature $T = 0.25$ GeV, the result of the free energy is still higher for $\gamma_g = 6\gamma_q$ than the value of $\gamma_g = 8\gamma_q$. The difference between the free energy is more distinct with increase in bubble size. Moreover, the calculation of photon production for hot and thermal region of QGP [11] such as the temperature at $T = 0.25$ GeV which is very hot QGP and round the transition temperature at $T = 0.17$ Gev and 0.15 GeV show the rate of production different. The photon spectrum is found to be
FIG. 5: The photon emission rate through ann, \( Y = \frac{E dN_{\text{ann}}}{dP dX} \), log\((Y)\) at thermal temperature \( T = 0.25 \text{ GeV}, 0.17 \text{ GeV} \) and 0.15 GeV at different \( \gamma_{q,g} \) through Fermi-dirac for \( q \) and \( \bar{q} \).

FIG. 6: The photon emission rate through comp, \( Y = \frac{E dN_{\text{comp}}}{dP dX} \), log\((Y)\) at thermal temperature \( T = 0.25 \text{ GeV}, 0.17 \text{ GeV} \) and 0.15 GeV at different \( \gamma_{q,g} \) through Fermi-dirac for \( q \) and \( \bar{q} \).

FIG. 7: WA80 collaboration of photon emission rate at LHC (CERN)

We are very thankful to Dr. R. Ramanathan and Dr. K.K. Gupta for their constructive suggestions and discussions.

Acknowledgments

We are very thankful to Dr. R. Ramanathan and Dr. K.K. Gupta for their constructive suggestions and discussions.
S. Sarkar, P. Roy, J. Alam, and B. Sinha, Phys. Rev. C 60 (1999) 054907.

[6] J. Kapusta, P. Lichard, and D. Seibert, Phys. Rev. D 44 (1991) 2774; Phys. Rev. D 47 (1993) 4171; P. Aurencche, F. Elis, R. Kobes, and H. Zaraket, Phys. Rev. D 58 (1998) 085003; J. Alam, S. Sarkar, T. Hatsuda, T. K. Nayak, and B. Sinha, Phys. Rev. C 63 (2001) 021901(R); R. Baier, H. Nakkagawa, A. Neigawa, and K. Redlich, Z. Phys. C 53 (1992) 433; S. Wang and D. Boyanovsky, Phys. Rev. D 63 (2001) 051702(R).

[7] G. D. Moore hep-ph/0403169; V. Ruuskanen in Quark-Gluon Plasma edited by R. C. Hwa, World Scientific, 1991.

[8] Wong in Intr. to High-Energy Heavy-Ion Collisions edited by C. Y. Wong, World Scientific, 1994.

[9] R. D. Pisarski, Nucl. Phys. B 309 (1988) 476; Phys. Rev. Lett. 63 (1989) 1129; B. Braaten and R. D. Pisarski, Nucl. Phys. B 337 (1990) 569.

[10] R. Ramanathan, A. K. Jha, S. S. Singh, R. Ramanathan, Y. K. Mathur, K. K. Gupta, and K. K. Gupta, Phys. Rev. C 70 (2004) 061408.

[11] J. Cleymans, J. Finghberg and K. Redlich, Phys. Rev. D 35 (1987) 2153.