



Theoretical Study of the Photons Production Kinetic In Hot Quark-Gluon Plasma Matter

Hadi J.M. Al-agealy

Rawnaq Qays Ghadhban

Mohsin A. Hassooni

Department of Physics, College of Education for Pure Sciences Ibn Al- Haitham, University of Baghdad, Baghdad, Iraq.

HadiAlagealy2016@gmail.com

Rownaq.qph@gmail.com

mohsin.a@ihcoedu.uobaghdad.edu.iq

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Abstract

In this paper, we study flow of photons rate production in a quark-gluon QG plasma. General theory of this study is based on the field theory for hard interaction. The kinetic of photons production from hard interaction in charm with anti-top to production photons with gluon $c\bar{t} \rightarrow \gamma g$ due to plasma phase at high temperatures (150, 200, 250, 300 and 350 MeV). It has been investigated and studied using the postulate of quantum chromodynamic theory QCD. The photons production rate of hard photons with ($E_\gamma = 1\text{GeV}$) are insensitive to strength coupling and depend mainly on the temperature of system T . Despite the different critical temperature (150 and 190 MeV) comes, we find that same order of flow rate photons magnitude in both cases. In both cases, the flow rate of photons production in the QG plasma is increased with increased temperature of system and photons energy and decreases with increases the strength coupling strength.

Key Word: Photons Production, Kinetic, Hot Quark-Gluon Plasma

1. Introduction

The photons are important valuable tools to probing hot matter in relativistic heavy-ion collisions RHIC at BNL and Larger Hadronic Collision LHC at CERN[1-2]. The photons have been emitted from the different mechanism such that prompt photons, thermal photons and jet-medium photons. Photons are emitted during the quark gluon plasma phase QGP and hadron gas Phase (HG) due to jets, and by decay of long-lived resonances into real photons [3]. Recently, the interaction of quark-gluon plasma has been achieved to understand the equilibrium state. Hard photons emission in both Compton and annihilation processes with having an energy large the temperature T of system [4]. The production of photons is



observable in higher energy relativistic heavy-ion collisions. The interaction of quark–gluon plasma in hot media has radiated thermal photons due to transverse momenta [5]. Hard photons are a important tool to investigate and study the characteristic and properties of quark matter in ultrarelativistic heavy-ion collision. It could be probing the dense system during interaction of quark-gluon plasma for a short time[6]. In this paper,we can find the relation between the photons rate and properties in $c\bar{t} \rightarrow \gamma g$ quark system in plasma media according to the quantum chromodynamic postulate theory using MATLAB program .

2.Theory

The production of gamma photons from plasma quark gluon interaction has been related to the retarded polarization of the gamma photon using field theory the number of photons emitted from quarks gluon plasma interaction per unit time and per unit volume is [7-8].

$$E \frac{dR_\gamma}{d^3K} = -\frac{1}{(2\pi)^3} F_B(E) \text{Im}(\Pi_\mu^\mu(E, q)) \tag{1}$$

where E is the energy of system ,q is momentum of quarks , $\Pi_\mu^\mu(E, q)$ is the retarded self-energy for photons emitted at temperature T and $F_B(E)$ is the Bose-Einstein distribution function for gluon and given by [9].

$$F_B(E) = \frac{\lambda_g}{e^{\frac{E}{T}} - 1} \tag{2}$$

Where λ_g is the fugacity of gluon .Substituting Eq.(2) in Eq.(1) to produce:

$$E \frac{dR_\gamma}{d^3K} = -\frac{1}{(2\pi)^3} \lambda_g \left(e^{\frac{E}{T}} - 1 \right)^{-1} \text{Im} \Pi_\mu^\mu(E, q) \tag{3}$$

The retarded propagators self-energy term related to photons emission according to spectral density $\rho(w, \bar{k})$ by relation [10].

$$\text{Im} \Pi_\mu^\mu(E, q) = -\frac{10\pi e^2}{3} \sum e_q^2 \left(e^{\frac{E}{T}} - 1 \right) \times \int \frac{d^3k}{(2\pi)^3} \int_{-\infty}^{\infty} dw \int_{-\infty}^{\infty} dw^\sim \delta(E - w - w^\sim) [F_{F(q)}(w) \cdot F_{E(\bar{q})}(\tilde{w})] \text{Tr}[\xi^\mu(k, p) \rho^*(w, \bar{k}) \rho(w - E, \bar{k} - \bar{p}) \xi^\nu(k, p)] \tag{4}$$

Where e_q^2 is square charge of quark , k is soft momentum of quark propagator, $k - P$ is the hard momentum of quark propagator , E is the energy of system , $\rho(w, \bar{k})$ and $\rho^*(w, \bar{k})$ are the spectral function and conjugate spectral function of quark, and $\xi^\mu(k, \bar{k}, -p) \xi^\nu(-\bar{k}, -k, p)$ are the propagation and conjugate function of quarks system

On the other hand, the $F_{F(q)}(w)$ and $F_{E(\bar{q})}(\tilde{w})$ are Fermi Dirac representation for quark and anti-quark respectively. The quark and anti-quark distribution are given by the Juttner distribution functions [8].

$$F(q) = \frac{\lambda_q}{e^{\frac{E_q}{T}} + 1} \text{ and } F(\bar{q}) = \frac{\lambda_{\bar{q}}}{e^{\frac{E_{\bar{q}}}{T}} - 1} \tag{5}$$

Since the trace of system can be reformation using [12].

$$\text{Tr}[\xi^\mu(k, \bar{k}, -p) \rho^*(w, \bar{k}) \rho(w - E, \bar{k} - \bar{p}) \xi^\nu(-\bar{k}, -k, p)] = -2\text{Tr}[\rho^*(w, \bar{k}) \rho(w - E, \bar{k} - \bar{p})] \tag{6}$$

Substituting Eq.(6) ,Eq.(5) in Eq.(4) to result:

$$\text{Im} \Pi_\mu^{R,\mu} = -\frac{10\pi}{3} e^2 \sum e_{qCD}^2 \left(e^{\frac{E}{T}} - 1 \right) \times \int \frac{d^3k}{(2\pi)^3} \int_{-\infty}^{\infty} \frac{dw}{2\pi} \int_{-\infty}^{\infty} \frac{dw^\sim}{2\pi} \delta(E - w - w^\sim) \lambda_q \lambda_{\bar{q}} \left[\frac{\left(e^{\frac{E_q}{T}} + 1 \right)^{-1} \left(e^{\frac{E_{\bar{q}}}{T}} - 1 \right)^{-1}}{w + w^\sim - ip} \right] 2\text{Tr}[\rho^*(w, \bar{k}) \rho(w - E, \bar{k} - \bar{p})] \tag{7}$$

The Eq.(6) can simply be using the integral Dirac function [11].

$$\int_{-\infty}^{\infty} \frac{dw^-}{2\pi} \delta(E - w - w^-) \frac{[(e^{\frac{E_1}{T}+1})^{-1}(e^{\frac{E_2}{T}-1})^{-1}]}{w+w^- - ip} \approx \int_{-\infty}^{\infty} \delta(E - w - w^-) \left[\left(e^{\frac{E_q}{T}+1} \right)^{-1} \left(e^{\frac{E_q}{T}-1} \right)^{-1} \right] dw^- \approx \left[\left(e^{\frac{E_q}{T}+1} \right)^{-1} \left(e^{\frac{E_q}{T}-1} \right)^{-1} \right] \quad (8)$$

Then Eq.(7) with Eq.(8) may be written as

$$Im \Pi_{\mu}^{R,\mu} = \frac{20\pi}{3} e^2 \sum e_{QCD}^2 \left(e^{\frac{E}{T}} - 1 \right) \times \int \frac{d^3k}{(2\pi)^3} \int_{-\infty}^{\infty} \frac{dw}{2\pi} \lambda_q \lambda_{\dot{q}} \left[\left(e^{\frac{E_q}{T}+1} \right)^{-1} \left(e^{\frac{E_{\dot{q}}}{T}-1-1} \right)^{-1} \right] \times Tr[\rho^*(w, \bar{k}) \rho(w - E, \bar{k} - \bar{p})] \quad (9)$$

Then Eq.(3-46) simply due to solve the trace using identity of spectral functions to obtained [12].

$$Im \Pi_{\mu}^{R,\mu} = -4\pi \frac{10\pi}{3} e^2 \sum e_{QCD}^2 \left(e^{\frac{E}{T}} - 1 \right) \times \int \frac{d^3k}{(2\pi)^3} \int_{-\infty}^{\infty} \frac{dw}{2\pi} \lambda_q \lambda_{\dot{q}} \left[\left(e^{\frac{E_q}{T}+1} \right)^{-1} \left(e^{\frac{E_{\dot{q}}}{T}-1} \right)^{-1} \right] \times \frac{1}{2k} \delta(\cos\theta - \frac{w}{k}) [\rho_+^*(w, \bar{k}) \left(-1 + \frac{w}{k} \right) + \rho_-^*(w, \bar{k}) \left(-1 - \frac{w}{k} \right)] \quad (10)$$

Since the quark –gluon plasma system has interested with large photon energy case have, $E_q + E_{\dot{q}} > E_\gamma \gg T$, that's can use an approximation to given.

$$\left(e^{\frac{E_q}{T}+1} \right)^{-1} \left(e^{\frac{E_{\dot{q}}}{T}-1} \right)^{-1} \approx e^{-\frac{E_q}{T}} e^{-\frac{E_{\dot{q}}}{T}} \approx e^{-\frac{(E_q+E_{\dot{q}})}{T}} \approx e^{-\frac{E_\gamma}{T}} \quad (11)$$

Then Eq.(10) simply to:

$$Im \Pi_{\mu}^{R,\mu} = -4\pi \frac{5}{12\pi^2} e^2 \sum e_{QCD}^2 \left(e^{\frac{E}{T}} - 1 \right) \times \int dk \int_{-\infty}^{\infty} \frac{dw}{2\pi} \lambda_q \lambda_{\dot{q}} \left[e^{-\frac{E_\gamma}{T}} \right] \times \frac{1}{k} \delta(\cos\theta - \frac{w}{k}) [\rho_+^*(w, \bar{k}) \left(-1 + \frac{w}{k} \right) + \rho_-^*(w, \bar{k}) \left(-1 - \frac{w}{k} \right)] \quad (12)$$

The Eq.(12) reformulated using $\int dk \frac{1}{k} \delta(\cos\theta - \frac{w}{k}) \approx \int k dk \theta$

$$Im \Pi_{\mu}^{R,\mu} = -4\pi \frac{5}{12\pi^2} e^2 \sum e_{QCD}^2 \left(e^{\frac{E}{T}} - 1 \right) \times \int k dk \int_{-\infty}^{\infty} \frac{dw}{2\pi} \lambda_q \lambda_{\dot{q}} \left[e^{-\frac{E_\gamma}{T}} \right] \times [\rho_+^*(w, \bar{k}) \left(-1 + \frac{w}{k} \right) + \rho_-^*(w, \bar{k}) \left(-1 - \frac{w}{k} \right)] \quad (13)$$

However the recursion relation of integral [11].

$$\int_{-\infty}^{\infty} \frac{dw}{2\pi} \rho_+^*(w, \bar{k}) \left(-1 + \frac{w}{k} \right) + \rho_-^*(w, \bar{k}) \left(-1 - \frac{w}{k} \right) = [\sigma_+(k) \left(-1 + \frac{w}{k} \right) + \sigma_-(k) \left(-1 - \frac{w}{k} \right)] + \beta_-(w, k) \times \theta(k^2 - w^2) \quad (14)$$

Then Eq.(13) with Eq.(14) lead to:

$$Im \Pi_{\mu}^{R,\mu} = -4\pi \frac{5}{12\pi^2} e^2 \sum e_{QCD}^2 \left(e^{\frac{E}{T}} - 1 \right) \times \int k dk \left[\lambda_q \lambda_{\dot{q}} \left[e^{-\frac{E_\gamma}{T}} \right] \right] \times [\sigma_+(k) \left(-1 + \frac{w}{k} \right) + \sigma_-(k) \left(-1 - \frac{w}{k} \right)] + \beta_-(w, k) \times \theta(k^2 - w^2) \quad (15)$$

The second term in integral (3-59) refers to the correction term and is given by [12]

The integral term in Eq. (15) lead to

$$\int k dk \beta_-(w, k) \times \theta(k^2 - w^2) k dk = m_q^2 \Omega_{con} \quad (16)$$

Where $\beta_{\pm}(w, k)$ is irrelevant for the cut term from Landau damping and is given by[12].

$$\int [\sigma_+(k) \left(-1 + \frac{w}{k} \right) + \sigma_-(k) \left(-1 - \frac{w}{k} \right)] k dk = 2m_q^2 \int_k^\mu \frac{w_+(k) - w_-(k)}{m_q^2} dk \quad (17)$$

Then Eq.(3-59) with definition integral in Eq.(3-67) and (Eq.(3-60) must to:

$$Im\prod_{\mu}^{R,\mu} = -4\pi \frac{5}{12\pi^2} 4\pi\alpha \sum e_{QCD}^2 \left(e^{\frac{E}{T}} - 1 \right) \times \lambda_q \lambda_{\bar{q}} \left[e^{-\frac{E_Y}{T}} \right] \left\{ 2m_q^2 \int_k^{\mu} \frac{w_+(k) - w_-(k)}{m_q^2} dk + m_q^2 \Omega_{con} \right. \quad (18)$$

The mass of quark is induced by QCD temperature by formula [13].

$$m_q^2 = \frac{g^2 C_f T^2}{8} = \frac{2\pi}{3} \alpha^{St} T^2 \quad (19)$$

And the integral in Eq.(18) is reduce to

$$2 \int_k^{\mu} \frac{w_+(k) - w_-(k)}{m_q^2} dk = \frac{2}{3} Ln \left(\frac{4E_Y T}{k_c^2} \right) \quad (20)$$

It may be inserting Eq.(20) and Eq.(19) in Eq.(18) to be reduced to.

$$Im\prod_{\mu}^{R,\mu} = -4\pi \frac{5}{12\pi^2} 4\pi\alpha \sum e_{QCD}^2 \left(e^{\frac{E}{T}} - 1 \right) \times \lambda_q \lambda_{\bar{q}} \left[e^{-\frac{E_Y}{T}} \right] \frac{2\pi}{3} \alpha^{St} T^2 \left\{ \frac{2}{3} Ln \left(\frac{4E_Y T}{k_c^2} \right) + \Omega_{con} \right. \quad (21)$$

However, it can mentioned here that:

$$\Omega_{con} = 1 \frac{43}{100} \quad (22)$$

Inserting the Eq. (22) in Eq. (21) to reduce:

$$Im\prod_{\mu}^{R,\mu} = -4\pi \frac{5}{12\pi^2} 4\pi\alpha \sum e_{QCD}^2 \left(e^{\frac{E}{T}} - 1 \right) \times \lambda_q \lambda_{\bar{q}} \left[e^{-\frac{E_Y}{T}} \right] \frac{2\pi}{3} \alpha^{St} T^2 \left\{ \frac{2}{3} Ln \left(\frac{4E_Y T}{k_c^2} \right) + 1 \frac{43}{100} \right. \quad (23)$$

The current rate of photons can be calculation by substituting Eq.(23) in Eq.(3) to results

$$E \frac{dR_{\gamma}}{d^3K} = \frac{1}{\pi^2} \frac{5}{9} \alpha \alpha^{St} \sum e_{QCD}^2 \times \lambda_g \lambda_q \lambda_{\bar{q}} T^2 e^{-\frac{E_Y}{T}} \left[\frac{2}{3} Ln \left(\frac{4E_Y T}{k_c^2} \right) + 1 \frac{43}{100} \right] \quad (24)$$

Where α is the electro strength constant, α^{St} is the strength coupling, e_{QCD}^2 is the square of electric charge of quarks system, λ_g is the fugacity of gluons, λ_q is the fugacity of quark, $\lambda_{\bar{q}}$ is the fugacity of anti-quark, T^2 is the square of temperature of system and E_Y is the photons energy. The strength coupling α^{St} is

$$\alpha^{St}(P) = \frac{6\pi}{(33-2N_{fi}) \ln \left(\frac{P_c}{T_c} \right)} \quad (25)$$

Where N_{fi} is the flavor quantum number, P_c is the momentum of photons system and the critical temperature T_c .

3.Results

Table (1) shows strength coupling spectra of interaction $c\bar{t} \rightarrow \gamma g$ system in plasma that is calculated according to quantum flavor number, critical temperature and temperature of system. To obtain the strength coupling, the momentum spectra of system were taken from experimental date $P_c = 1, 2, 3, 4$ and 5 GeV [14] and elected the critical temperature $T_c = 150$ MeV and $T_c = 190$ MeV. It should be mentioned at this point that quantum flavor number was calculated using the summation $\sum_{i=1}^6 N_{fi} = 6$ and estimation the total electric charge of quark using $\sum_f e_f^2 = \left(\frac{2}{3}\right)^2 + \left(-\frac{1}{3}\right)^2 = \frac{5}{9}$. The strength coupling was calculated using Eq.(25) and inserting $N_{fi} = 6$, $P = 1, 2, 3, 4$ and 5 GeV and elected $T_c = 150$ MeV and $T_c = 190$ MeV.

However, the flow photonic rate $E_{\gamma} \frac{dR_{\gamma}}{d^3q}$ has calculated using Eq. (24) at critical temperature $T_c = 150$ MeV using fugacity of quark $\lambda_q = 0.85$, anti-quark $\lambda_{\bar{q}} = 0.9$ and gluon $\lambda_g = 0.08$ with various temperature $T = 150, 200, 250, 300$ and 350 MeV with MATLAB program. Results are

listed in **table (2)** with $T_c = 150$ MeV and table (3) with $T_c = 190$ MeV. **Figures (1) and (2)** show the flow of photons rate plotted verse photons energy.

Table 1. Strength coupling quantum color at $T_c = 150$ MeV and $T_c = 190$ MeV.

Critical Temperature	The $c\bar{t} \rightarrow \gamma g$ system				
	$P_c=1$ GeV	$P_c=2$ GeV	$P_c=3$ GeV	$P_c=4$ GeV	$P_c=5$ GeV
150 MeV	0.7642	0.5597	0.4840	0.4416	0.4135
190 MeV	0.8730	0.6159	0.5254	0.4758	0.4433

Table 2. Result of flow photonic rate $E_\gamma \frac{dR_\gamma}{d^3q}$ in $c\bar{t} \rightarrow \gamma g$ at $T_c = 150$ MeV with $\lambda_q = 0.85$ $\lambda_{\bar{q}} = 0.9$, $\lambda_g = 0.08$.

E_γ, Gev	$E_\gamma \frac{dR_\gamma}{d^3q} (\text{GeV}^2 \text{fm}^4)^{-1}$				
	$T=150$ MeV	$T=200$ MeV	$T=250$ MeV	$T=300$ MeV	$T=350$ MeV
	$\alpha^{St}=0.7642$	$\alpha^{St}=0.5597$	$\alpha^{St}=0.4840$	$\alpha^{St}=0.4416$	$\alpha^{St}=0.4135$
1.0	8.6587E-10	6.6690E-09	2.5694E-08	6.7689E-08	1.4174E-07
1.5	3.5605E-11	6.2224E-10	3.9304E-09	1.4403E-08	3.8180E-08
2.0	1.3896E-12	5.5434E-11	5.7542E-10	2.9372E-09	9.8661E-09
2.5	5.2875E-14	4.8277E-12	8.2441E-11	5.8652E-10	2.4976E-09
3.0	1.9825E-15	4.1489E-13	1.1662E-11	1.1568E-10	6.2461E-10
3.5	7.3629E-17	3.5347E-14	1.6361E-12	2.2632E-11	1.5497E-10
4.0	2.7164E-18	2.9933E-15	2.2819E-13	4.4028E-12	3.8236E-11

Table 3. Result of photonic rate $E_\gamma \frac{dR_\gamma}{d^3q}$ in $c\bar{t} \rightarrow \gamma g$ at $T_c = 190$ MeV with $\lambda_q = 0.85$ $\lambda_{\bar{q}} = 0.9$, $\lambda_g = 0.08$

E_γ, Gev	$E_\gamma \frac{dR_\gamma}{d^3q} (\text{GeV}^2 \text{fm}^4)^{-1}$				
	$T=150$ MeV	$T=200$ MeV	$T=250$ MeV	$T=300$ MeV	$T=350$ MeV
	$\alpha^{St}=0.8730$	$\alpha^{St}=0.6159$	$\alpha^{St}=0.5254$	$\alpha^{St}=0.4758$	$\alpha^{St}=0.4433$
1.0	9.3956E-10	7.1020E-09	2.7156E-08	7.1233E-08	1.4872E-07
1.5	3.8906E-11	6.6529E-10	4.1670E-09	1.5198E-08	4.0157E-08
2.0	1.5243E-12	5.9405E-11	6.1116E-10	3.1041E-09	1.0391E-08
2.5	5.8152E-14	5.1815E-12	8.7669E-11	6.2051E-10	2.6330E-09
3.0	2.1845E-15	4.4580E-13	1.2413E-11	1.2248E-10	6.5896E-10
3.5	8.1247E-17	3.8015E-14	1.7426E-12	2.3977E-11	1.6358E-10
4.0	3.0009E-18	3.2215E-15	2.4319E-13	4.6667E-12	4.0379E-11

4. Discussion

We discuss behavior of photons flow rate production in quark anti quark interaction processes from a non-equilibrated QG plasma at finite potential with effect of coupling strength constant. The results indicate important information concerning photon produced as a signature of QG plasma. The photons flow rate of QG interaction with quantum quark flavor number $N_f = 10$ are discussed as follows. **Figure (1)** indicate flow of photon production rate at temperature $T = 0.150, 0.200, 0.250, 0.300$ and 0.350 GeV cross annihilation process for

quarks quantum flavor number $N_f = 10$. It is found the flow photons rate increased function of photons energy at critical temperature $T_C = 150$ MeV. It has been taken the $T = 0.350$ GeV to find large effect of flow photons rate contribution due to increase the photons energy (1, 1.5, 2, 2.5, 3, 3.5 and 4 GeV). The strength coupling value also effect on contribute of the flow production rate and the rate is increased due to decreased the strength coupling and it has a larger flow rate produced at very higher temperature $T=0.350$ GeV and low strength coupling.

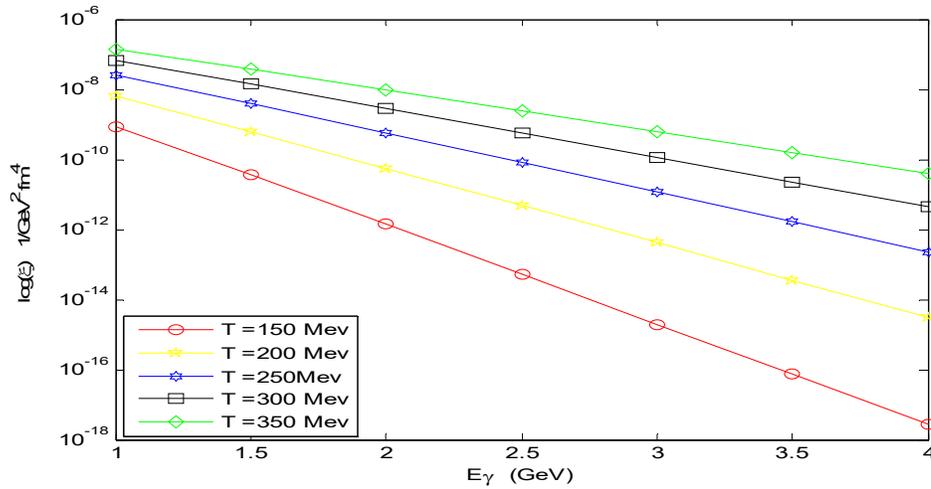


Figure 1. Photon flow rate production through $c\bar{c} \rightarrow \gamma\gamma$ annihilation process due to E_γ at $T_c = 150$ MeV, $N_f = 10$, for with $\lambda_q=0.85$ $\lambda_{\bar{q}} = 0.9$, $\lambda_g = 0.08$

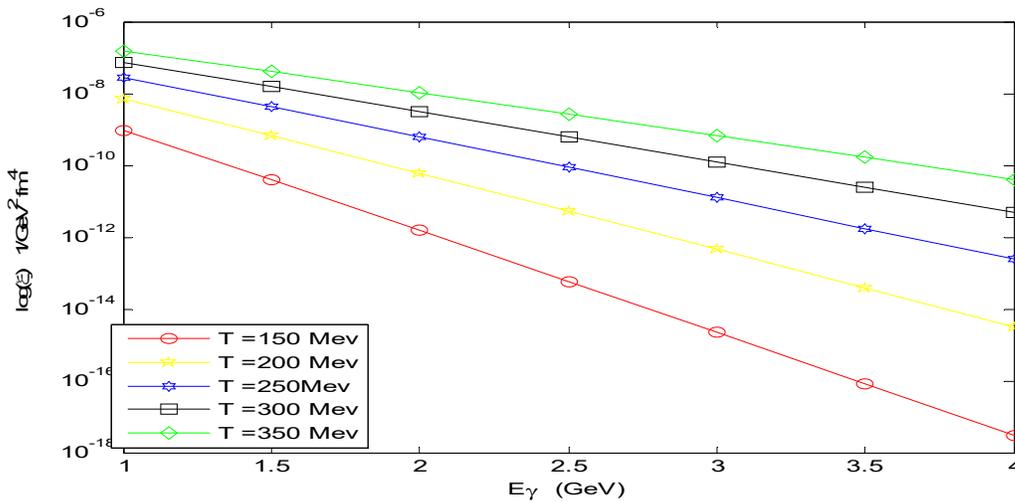


Figure 2. Photon flow rate production through $c\bar{c} \rightarrow \gamma\gamma$ annihilation process due to E_γ at $T_c = 190$ MeV, $N_f = 10$, with fugacity of quark $\lambda_q=0.85$ anti-quark $\lambda_{\bar{q}} = 0.9$ and gluon $\lambda_g = 0.08$

Similarly, in figure (2) it can be shown that the flow rate of photon emission is at same temperatures through the interaction of quark gluon at another critical temperature $T_C = 190$ MeV. The flow rate of photons yield is less increased with photons energy compare with

figure (1) in same interaction process. In comparison with **figure (1)**, the flow photons rate shows better outcome. This implies that critical temperature has more effect beside the strength coupling. In figure (2), we can show the less increases in contributions to the flow rate of photon at the same order of quantum flavor number as results of different in the strength coupling of QG plasma process. The flow rate increases with the effect of decreases strength coupling but decreases as temperature decreases. It is found that low temperature $T=150$ MeV produces less flow rate of photons in comparison to the large temperature $T=350$ MeV during the QG plasma. This shows that the flow rate produced by QG plasma process is low in high strength coupling in comparison to the low strength coupling in same processes. The results in both **tables (1)** and (2) and **figures (1)** and (2) do not show any huge of flow rate of photons in QG plasma process due to contributed by fugacities of quarks and gluon. In $c\bar{t} \rightarrow \gamma g$ system, the flow rate contribution from $T_c=150$ MeV is less than flow rate contribution from $T_c=190$ MeV over QG plasma process. Overall results are less effective in the case of critical temperature which compared with photons energy and strength coupling. Finally, in both figures (1) and (2), we consider the QG plasma interaction has large effect with photons energy and strength coupling and less effect with critical temperature. It is found that the flow rate of photons due to $T_c=190$ MeV is large in comparison to the $T_c=150$ MeV. Also, it is found a large flow photons rate due to same fugacity.

5. Conclusion

In conclusion the flow rate of photons yield is evaluated by integrated the flow rate over plasma phase. The calculation of flow rate of photons production as a function of photons energy incorporating with strength coupling and critical temperature. So, the flow rate of photons emission from a QG plasma system play an important role in the investigation of photon emission from higher energy collision.

It is found that large increase of flow photons production rate with decreased strength coupling and with increasing the temperature T and critical temperature at QG plasma system. Therefore, the flow photon rate is important for giving the information to create quark-gluon plasma media and supply more knowledge for the study and understanding of QGP interaction.

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