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Abstract. In this paper, the thermal photon rate generated by the interaction between a charm quark beam and a gluon in cg→ugγ plasma is studied using a computational approach. The quantum chromodynamics theory of quark-gluon collisions is used to investigate thermal photon emission. In the theoretical computational approach, quark charge flavour quantum number, strength coupling and thermal photon rate are calculated considering critical energy Tc=160 MeV, thermal energy (200-600) MeV, quark and gluon annihilation, photon energy in the range (0.75-10.25) GeV parameter to calibrate and study the photon rate spectrum. Calculation of the thermal photon rate produced by cg→ugγ from the QGP material consisting of quark-gluon plasma. It was found that in collisions it increases with increasing thermal energy, decreasing coupling strength and decreasing photon energy. The thermal photon rate in cg→ugγ increases slightly to a large at photon energyE≤2 GeV and reach to maximum at E=0.75 GeV compared to reaching a small at energyE≫5 GeV and reaching a minimum at energy=10.25 GeV in cg→ugγ systems

Keywords: Spectrum, Photon Emissivity, Quantum Chromo Dynamic QCD, Charm Quark, Strange Quark.

INTRODUCTION

Elementary particle physics is one of the main fields that deals with the basic components of matter and their interactions in physics and uses a much more scientific approach to study and investigate many facts related to constructive nature. Many very successful theories have been tested and deduced to understand and examine the structure of nucleons using the interaction between quarks and gluons and the formation of the universal phase after the Big Bang phase [1-2]. the Quark-Gluon Plasma (QGP) is matter can be produced from deconfined quarks and gluons using main experimental developed at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory and the Large Hadron Collider (LHC) at CERN [3]. However, quark particles are fermions, which Gell-Mann introduced into three generations (up, down), (strange, charm) and (up, down), which have six flavours of quantum numbers [4]. In contrast, gluons are bosons that exchange particles that are associated with colour charge and direct the strong force between quarks, carrying eight colour and anti - colour gluons at the same time[5].In collisions, hadrons are produced at high energy by a fireball of quark-gluon plasma (QGP), and the main idea of heavy ion collisions is to study and create strong interacting matter, which is obtained by converting confined matter (hadron state) into a free deconfinement state of quark-gluon[6]. Experimentally, the strong interaction is one of the four known forces in physics and has been described and studied by quantum chromodynamics (QCD) according to quantum field theory [7]. Quark-gluon plasma is a state of matter that is thought to have existed in the early universe for a short time up to microseconds after the Big Bang in a few meters in volume ~100 cubic micrometers. The quark-gluon plasma state of matter cannot be directly detected [8]. Elementary particles have been studied using a variety of theoretical approaches, including quantum chromodynamics, which is the basis of the Standard Model. In 1970, the Standard Model began to take shape, after the discovery of asymptotic freedom and the introduction of the possibility of renormalization and the interaction between the strong and weak interactions [9-10]. Photons are a key versatile tool for providing direct information about quark-gluon plasma (QGP). The sources of photon emission are hadron decays and direct photons, the contribution of photon decays being larger than that of direct photons, and providing information available for particle reconstruction [11]. The strength coupling is the main parameter that controls the emission of photons from a quark-gluon interaction in a QCD medium. Quark-gluon plasma (QGP) has a smaller force coupling in the weakly coupled quark to the gluon and vice versa, indicating the influence of the force coupling effect on the photon rate estimation [12]. Quarks and gluons were not found freely unlike molecules and atoms, but were confined in the hadronic state, which was exactly like the north and south magnetic pole decays and was never isolated from each other [13]. Furthermore, the emission of thermal photons due to quark-gluon interaction in QGP material can be observed in heavy ion experiments and discussed using phase space distributed using Bose-Einstein and Fermi-Dirac distributions [14].In this work, the thermal photon produced by the collision of a quark with a gluon at higher energy is studied and evaluated via QCD theory using a computational approach to estimate the coupling strength of their collision in two systems of cg→ugγ and cg→dgγ interactions with flavour numbers n_F=5 and 6,respectivelly.

THEORY

The thermal photons emission from quark-gluon collisions in momentum P and energy E is giving by [15].

$$\Gamma_{qg}^{T}(E,P) = \frac{-2}{(2\pi)^3}\frac{\lambda_g}{e^{\frac{E}{T}}-\lambda_g}\mathrm{Im}\prod_{qg}^{T}(E,P) \qquad (1)$$

Where λ_g , E and T are fugacity of gluon, photons energy and temperature of system and $\mathrm{Im}\prod_{qg}^{T}(E,P)$ is imaginary of the retarded polarization of photons gives by [16].

$$\mathrm{Im}\prod_{qg}^{T}(E,P) = \frac{N_c C {g_e}^2 {g_c}^2 T|\mathrm{I_{se}}|}{\pi^4 E^2}\int_0^\infty \left(F_q(E-P)-F_q(P)\right)((E-P)^2+P^2)\,dP \qquad (2)$$

Where N_c and C are color number and Casimir operator, g_e and g_c are quantum electrodynamics and chromodynamic couplings, $F_q(E-P)$and $F_q(P)$ are Juttner distribution function of quark, $|\mathrm{I_{se}}|$ is the self-integral of system. The self-integral in Equation. (2) reduced to [17].

$$\mathrm{I_{se}} = \mathrm{I_T} - \mathrm{I_L} \qquad (3)$$

Where $\mathrm{I_T}$ and $\mathrm{I_L}$ are transverse and longitudinal self-integral. Under assume Introduce electric charge $\sum Q_q^2$ of quark in Equation. (2) together Equation. (3) to become.

$$\mathrm{Im}\prod_{qg}^{T}(E,P) = \frac{N_c C {g_e}^2 {g_c}^2 T|\mathrm{I_{se}}|\sum Q_q^2}{\pi^4 E^2}\int_0^\infty \left(F_q(E-P)-F_q(P)\right)((E-P)^2+P^2)\,dP \qquad (4)$$

The Juttner distribution function $F_q(p-E)$ and $F_q(P)$ are function of chemical potential V_q and quark fugacity λ_q and writes by [18].

$$F_q(p-E) = \lambda_q(e^{\frac{(E-p-V_q)}{T}}+\lambda_q)^{-1} \qquad (5)$$

And

$$F_q(P) = \lambda_q(e^{\frac{(p+V_q)}{T}}+\lambda_q)^{-1} \qquad (6)$$

Insert Equation. (5) and Equation. (6) in Equation. (3-4) to obtained.

$$\mathrm{Im}\prod_{qg}^{T}(E,P) = \frac{N_c C {g_e}^2 {g_c}^2 T|\mathrm{I_{se}}|\lambda_q\sum Q_q^2}{\pi^4 E^2}\int_0^\infty \left(F_q(E-P)-F_q(P)\right)((E-P)^2+P^2)\,dP \qquad (7)$$

The final term can be expanded to

$$(P^2+(E-P)^2) = E^2-2EP+2P^2 = 2P^2+E^2-2EP \qquad (8)$$

The Equation.(7) togother Equation. (8) gives.

$$\mathrm{Im}\prod_{qg}^{T}(E,P) = \frac{N_c C {g_e}^2 {g_c}^2 T|\mathrm{I_{se}}|\lambda_q\sum Q_q^2}{\pi^4 E^2}\int_0^\infty \left(F_q(E-P)-F_q(P)\right)(2P^2+E^2-2EP)\,dP \qquad (9)$$

Under assume $\alpha = \frac{(E-p-V_q)}{T}$ and $\beta = \frac{(p+V_q)}{T}$ the two exponentials in Equation. (9) reduced to

$$(e^{\frac{(E-p-V_q)}{T}}+\lambda_q)^{-1} = e^{-\alpha}-\lambda_q e^{-2\alpha}+{\lambda_q}^2 e^{-3\alpha} \qquad (10)$$

$$(e^{\frac{(p+V_q)}{T}}+\lambda_q)^{-1} = e^{-\beta}-\lambda_q e^{-2\beta}+{\lambda_q}^2 e^{-3\beta}\text{-} \qquad (11)$$

Insert Equation. (10) and Equation. (11) in Equation. (9) to results.

$$\mathrm{Im}\prod_{qg}^{T}(E,P) = \frac{N_c C {g_e}^2 {g_c}^2 T|\mathrm{I_{se}}|\lambda_q\sum Q_q^2}{\pi^4 E^2}\int_0^\infty \sum_{n=0}^{\infty}\lambda_q^n\,(e^{-(n+1)\alpha}-e^{-(n+1)\beta}\,(2P^2+E^2-2EP)\,dP \qquad (12)$$

The integral in Equation. (12) can solve to results

$$I = \sum_{n=1}^{\infty}\left(e^{\frac{-n(E-V_q)}{T}}-e^{\frac{-V_q}{T}}\right)\left(2\frac{{\lambda_q}^n}{n^3}\Gamma(3)T^3+\frac{{\lambda_q}^n}{n}E^2T\Gamma(1)-2\frac{{\lambda_q}^n}{n^2}\mathrm{E}T^2\Gamma(2)\right) \qquad (13)$$

Inserting Equation. (13) in Equation. (12) to obtain.

$$\mathrm{Im}\prod{}_{qg}^{T}(E,P) = \frac{N_c C {g_e}^2 {g_c}^2 T|\mathrm{I_{se}}|\sum Q_q^2}{\pi^4 E^2}I \qquad (14)$$

The Casimir factor C of the fundamental representations of the group relative to color number N_c is given by [19].

$$C = \frac{(N_c^2-1)}{2N_c} = \frac{4}{3} \quad (15)$$

The running coupling constant parameter is [20].

$$\alpha_s^{qg} = \frac{g^2(Q)}{4\pi} \quad (16)$$

Inserting Equation. (15) and Equation. (16) in Equation. (14) to results.

$$\mathrm{Im}\prod{}_{qg}^{T}(E,P) = \frac{4N_c g_e{}^2 g_c{}^2 T|\mathrm{I_{se}}|\lambda_q \sum Q_q^2}{3\pi^4 E^2} I \quad (17)$$

However, the electrodynamics coupling constant α_e is [21].

$$\alpha_e = \frac{g_e{}^2}{4\pi} \quad (18)$$

Inserting Equation.(18) in Equation.(17) to produce.

$$\mathrm{Im}\prod{}_{qg}^{T}(E,P) = \frac{64N_c 4\pi\alpha_e 4\pi\alpha_s^{qg} T|\mathrm{I_{se}}|\lambda_q \sum Q_q^2}{3\pi^4 E^2} I \quad (19)$$

The expression in Equation.(19) can be simply to write

$$\mathrm{Im}\prod{}_{qg}^{T}(E,P) = \frac{64N_c\alpha_e\alpha_s^{qg} T|\mathrm{I_{se}}|\lambda_q \sum Q_q^2}{3\pi^2 E^2} I \quad (20)$$

insert Equation.(20) in rate form in Equation.(3-1) to write at $N_c = 3$.

$$\Gamma_{qg}^{T}(E,P) = \frac{\lambda_g}{e^{\frac{E}{T}}-\lambda_g} \frac{16N_c\alpha_e\alpha_s^{qg} T|\mathrm{I_{se}}|\lambda_q \sum Q_q^2}{\pi^5 E^2} I \quad (21)$$

The strength coupling constant is given by [22].

$$\alpha_s^{qg}(\mu^2) = \frac{12\pi}{(33-2n_F)ln(\frac{8T}{T_c})^2} \quad (22)$$

Where T is the heat energy and T_c is the critical temperature.

RESULTS

The computational approach to predicting thermal photon rate data using computational techniques and methods for studying the dynamics of photon emission from quark-gluon collisions utilizing the theory of quantum chromodynamics is indicated. The thermal photon spectrum of a quark-gluon collision depends on the coupling strength, the flavour number, the charge of the quarks, the number of colours, the thermal energy of the collision, the velocity of the quark and gluon, the energy of the photon, and the chemical potential of the system's reaction. Quantum QCD theory provides a good tool for achieving this. Calculate the coupling strength by estimating the quark charge and flavour number. The total flavor number of $cg \to ug\gamma$ collision can be estimation using summation of flavor number $N_f = \sum_n^m N_{Fn}$ using Table (1) for charm $n_c = 4$ and $n_u = 1$ for up quark, results is $N_F = 4 + 1 = 5$. Calculate the thermal photon rate, the coupling strength can be calculated by estimating the flavour number, critical temperature and thermal energy of the quark-gluon collision in the system.

TABLE 1. Properties of three generations of quarks [23].

Quark generation	Name of Quarks	Mass	Charge	N_F
First	Up (u)	$2.3^{+0.7}_{-0.5}\, MeV/c^2$	$+{}^2/_3\ e$	1
	Down (d)	$4.8^{+0.5}_{-0.3}\, MeV/c^2$	$-{}^1/_3\ e$	2
Second	Strange (s)	$95 \pm 5\, MeV/c^2$	$-{}^1/_3\ e$	3
	Charm (c)	$1.275 \pm 0.025\, GeV/c^2$	$+{}^2/_3\ e$	4
Third	Bottom (b)	$4.18 \pm 0.03\, GeV/c^2$	$-{}^1/_3\ e$	5
	Top (t)	$173.2 \pm 0.9\, GeV/c^2$	$+{}^2/_3\ e$	6

The strength coupling calculation for quarks-gluon interaction at collision required the estimation of critical temperature and thermal energy system. The critical temperature can be limited to 160 MeV using bag constant $B^{\frac{1}{4}} = 265$ MeV [24] and thermal energy of quark-gluon collision in range (200,225,250,275,300,325,3,375,400,425,450,475,500,525,550,575 and 600) MeV.

The strength coupling evaluates using Eq. (22) taken account $T_c = 160$MeV, flavor number $n_f = 5$ and temperature of system in range (200-600) MeV, results show in table (2) for $cg \to ug\gamma$ system.

TABLE 2. The Strength Coupling Calculation for $cg \to ug\gamma$ System using the Critical Temperature $T_c = 160$MeV.

T Mev	Running strength couplingα_s^{qg}(T)
200	0.35598
225	0.33866
250	0.32453
275	0.31272
300	0.30268
325	0.29398
350	0.28637
375	0.27963
400	0.27361
425	0.26818
450	0.26325
475	0.25876
500	0.25464
525	0.25083
550	0.24731
575	0.24404
600	0.24098

TABLE.3 Rate of Thermal Photon $\Gamma_{qg}^{T}(E,P)$ Emission from $cg \to ug\gamma$ Interaction at $T_c = 160$ MeV

E Gev	T Mev								
	200	250	300	350	400	450	500	550	600
0.75	3.22E-11	1.16E-10	2.85E-10	5.69E-10	9.90E-10	1.57E-09	2.33E-09	3.30E-09	4.49E-09
1.5	1.43E-15	7.85E-14	6.00E-13	2.16E-12	5.00E-12	8.17E-12	8.62E-12	5.80E-13	2.48E-11
2.25	1.07E-15	2.40E-14	2.05E-13	9.89E-13	3.308-12	8.60E-12	1.86E-11	3.52E-11	5.95E-11
3	2.44E-17	1.14E-15	1.60E-14	1.11E-13	4.95E-13	1.63E-12	4.29E-12	9.62E-12	1.90E-11
3.75	5.01E-19	4.94E-17	1.15E-15	1.15E-14	6.75E-14	2.76E-13	8.72E-13	2.27E-12	5.13E-12
4.25	3.75E-20	6.10E-18	1.98E-16	2.53E-15	1.78E-14	8.40E-14	2.98E-13	8.55E-13	2.09E-12
5	7.72E-22	2.66E-19	1.43E-17	2.62E-16	2.42E-15	1.41E-14	5.95E-14	1.97E-13	5.43E-13
5.75	1.61E-23	1.18E-20	1.04E-18	2.73E-17	3.32E-16	2.39E-15	1.19E-14	4.549-14	1.41E-13
6.25	1.23E-24	1.48E-21	1.836-19	6.12E-18	8.88E-17	7.37E-16	4.12E-15	1.72E-14	5.76E-14
7	2.60E-26	6.66E-23	1.364-20	6.50E-19	1.24E-17	1.27E-16	8.37E-16	4.01-15	1.51E-14

7.75	5.57E-28	3.02E-24	1.02E-21	6.97E-20	1.74E-18	2.19E-17	1.715-16	9.45E-16	3.99E-15
8.25	4.31E-29	3.86E-25	1.82E-22	1.58E-20	4.71E-19	6.84E-18	5.98E-17	3.61E-16	1.65E-15
9	9.35E-31	1.77E-26	1.382-23	1.71E-21	6.68E-20	1.20E-18	1.24E-17	8.58E-17	4.39E-16
9.75	2.04E-32	8.19E-28	1.05E-24	1.87E-22	9.52E-21	2.10E-19	2.57E-18	2.05E-17	1.17E-16
10.25	1.60E-33	1.06E-28	1.90E-25	4.28E-23	2.61E-21	6.62E-20	9.06E-19	7.89E-18	4.89E-17

The charge of quarks in $cg \rightarrow ug\gamma$ system can be computed used the summation of all charge for charm and up quarks in system $\sum Q_q^2 = (\frac{2}{3})^2 + (\frac{2}{3})^2 = {}^8\!/_9$. A computational calculation of the thermal photons spectra emission from charm quark interaction with gluon in collision process using the Eq.(21) and MATLAP simulation taken fine structure $\alpha_e = \frac{1}{137}$, $I_{se} \approx 1$ $\lambda_q = 0.02$ [25] ,$\lambda_g = 0.9$[25] and chemical potential $V_q = 284$MeV[25] ,results show in table (3) and figure (1) for $cg \rightarrow ug\gamma$ system

DISCUSSION

A computation method has been used to evaluate of the thermal photon emission from the collision of charm quark with gluon in quark-gluon plasma using a mathematical approach depends on quantum chromodynamics theory QCD using the critical temperature 160MeV and varouse photons energy (0.75-10.25) GeV with finit fugacity 0.09 and 0.02 for gluon and quark, respectivelly. The calculation of the strength coupling and the thermal photon rate of the thermal energy at range $200MeV \leq T \leq 600MeV$ has been performed .Table(2) shows that strength coupling α_s^{qg}(T) of $cg \rightarrow ug\gamma$ system was decreing with increasig the temperature of collision quark gluon plasma ,this indicated the effect of confinement and asymptomatic behavior of charm and up quarks in collision system with concerning the fact of low photons rate at increase strength coupling of quarks . The strength coupling α_s^{qg}(T)of $cg \rightarrow ug\gamma$ interaction reach to miximum values0.35598 at 200 MeV and reach to minimum 0.24098 at 600 MeV vice versa. The phenomena of confinement and asymptotic freedom indicate that the behaviour of quarks depends on the concepts of quantum chromodynamics (QCD), which show that quarks are almost inseparable at low energies ($\approx 200\ MeV$) while quarks behave like free particles at high energies$\approx 600\ MeV$, and this unique behaviour determines the strong force.On the other hand, confining quarks to asymptotic freedom has enhanced the understanding of the structure of hadrons and high-energy particle collisions, and has enabled accurate calculations in QCD. Furthermore,the strength coupling behavour with variety thermal energy of system and finit critical temperature 160MeV of of $cg \rightarrow ug\gamma$ system is limited the thermal photon emission from collision charm quark with gluon in plasma phase. The thermal photon rate of charm quark-gluon collision is obtained by integrating Eq. (13) over the previously determined momentum of the photons P. The thermal photon emission rate from the interaction of charm quarks with gluons for photon energy (0.75 GeV to 10.25 GeV) and temperature in the range of 200 MeV to 600 MeV for the $cg \rightarrow ug\gamma$ system was obtained using Eq. (21).In short, the rate of thermal photons produced by the $cg \rightarrow ug\gamma$ reaction slows down as the photon energy increases and the photons in the QGP material will decrease.Table(3) show the spectrum of thermal photon rate at energy $E = o.75$GeV was larger than thermal photon rate in $E = 10.25$GeV ,this indicated for energy $E = 10.25\ GeV$ the $cg \rightarrow ug\gamma$ system emitted photons less than at $E = o.75$GeV .On the other hand ,the emission of photons by collision of charm quark with gluon increases with increases thermal energy of system and vice versa. As a result, the number of flavors and charge of quarks greatly affected the coupling force by decreasing or increasing but decreasing the force resulted in more photons being emitted at lower photon energy. Moreover, the emission of thermal photons occurred at a higher thermal energy and lower force coupling, which would be good knowledge about the confinement and asymptotic behaviour of quarks and gluons to visualize the nature of the nuclear force. Indeed, the emissions thermal photon from $cg \rightarrow ug\gamma$ system was most probable at $E \leq 2$GeV and increase with decreasing strength coupling for quarks in the interval 1-10 GeV. the spectral thermal photons rate of the $cg \rightarrow ug\gamma$ system emerging by energy of photons emission are represented in tables (3). As expected, the photon emission rate from the quark-gluon interaction is fascinating at high energy production in a small region occurring in the system around the QGP material. In general, the emission of thermal photons will increase as the thermal energy increases and the coupling strength of the system decreases, and a large photon rate appears where the photon energy is smaller than 2-3 GeV, reaching a maximum at E=0.75 GeV to indicate that cross-section of charm quark –gluon reaction in photon energy 1 GeV is most probable comparing cross section in 10.25 GeV

CONCLUSION

In conclusion, the competition approach model has been presented to estimate the thermal photon emission rate from Charm Quark interaction with Gluon and analyses the spectral intensity using quantum chromodynamic theory. The computational approach to thermal photon rate generation is an effective complement to experimental study and, in some cases, is important for estimating radiation parameters in many practical applications. The calculation of the thermal photon rate of the quark-gluon plasma process is enhanced by coupling the strength, flavour number, solubility, and thermal energy of the QGP and the energy of the photons, giving a more stable advantage in the formation of the quark-gluon plasma. The thermal photon mass was calculated by combining the quark-gluon charm and spectral collision process and was a function of the thermal energy, force coupling and photon energy. The emission of thermal photons increases as the thermal energy of the interacting system increases and the strength of the coupling between quarks and gluons in the system decreases. Hence, the consideration of quark-gluon quantum chromodynamics theory plays an important role in calculating the thermal photon rate at high energy. Therefore, this theoretical calculation can provide results to improve experimental and other theoretical results.

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