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Study of Effect of Coupling Constant on the Rate of Photons Emission from Quark-Gluon System

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Abstract :

In this paper, the rate of photons emission from quark-gluon interaction is evaluated and studied based on the quantum chromodynamics theory. The photons emission rate is calculated for charm and gluon interaction $cg \rightarrow s\gamma$ system with critical temperature T_C=0.1271195803 and T_C=0.1412439781GeV and system temperature (185-305)MeV and photon energy 1≤ E_γ ≤3.5GeV . Here the critical temperature and coupling strength are supposed to effect significantly on photons emission rate from cg interaction, which can form strange and photons emission state. It was expected that the increase in the yield of photons emitted with the decrease in the coupling strength for the interaction of quarks due to the increase in the critical temperature from (0.1271195803 - 0.1412439781) GeV.

Keywords: photons emission, quark-gluon interaction, coupling strength.

دراسة تأثير ثابت الاقتران على معدل انبعاث الفوتونات من نظام كوارك-جلون

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مستخلص:

في هذا البحث، تم تقييم ودراسة معدل انبعاث الفوتونات من تفاعل كوارك-جلون بالاعتماد على النظرية الديناميكية اللونية الكمية . تم حساب معدل انبعاث الفوتونات لتفاعل الكوارك الساحر مع الجلون لنظام $cg \rightarrow s\gamma$ مع درجة حرارة حرجة T_C = 0.1271195803 و T_C = 0.1412439781GeV ودرجة حرارة النظام (185-305)MeV وطاقة الفوتون 1≤ E_γ≤3.5GeV تم افتراض درجة الحرارة الحرجة وقوة الاقتران لتؤثر بشكل كبير على معدل انبعاث الفوتونات الناتجة من تفاعل الساحر-جلون والتي يمكن ان تشكل كوارك الغريب مع مستوى انبعاث الفوتونات. ومن المتوقع ان يكون السبب في زيادة محصول الفوتونات المنبعثة مع النقصان في قوة الاقتران لتفاعل الكواركات يعود الى الزيادة في درجة الحرارة الحرجة من (0.1271195803-0.1412439781)GeV.

الكلمات المفتاحية: انبعاث الفوتونات، تفاعل كوارك-غلون، قوة الاقتران .

Introduction

Since the ancient times, humans tried to explaining the material would with all its complexities. The starting point was the belief of the Greek philosopher Democritus that there must be an indivisible part, which he called the atom [1]. Our current knowledge of the internal structure of atoms is the result of many experiments and theoretical models where the electron was discovered by J.J. Thomson [2] and through Rutherford scattering experiments it was known that most of the mass of the atom is concentrated in the nucleus and that the nucleus consists of a proton and a neutron[3]. In twentieth-century physics began directing their attention to elementary particle physics, which is considered one of the most important branches of physics and As a result a list of many elementary particles appeared and grew rapidly [4]. In 1964, George Zweig and Gell-Mann presented the quark model, and that every particle that contains a quark is classified as a hadron, and that the hadron is divided into mesons consisting of quarks, antiquarks, and baryons consisting of three quarks [5]. Elementary particles are classified according to standard model into fermions and bosons. Quarks and lepton are fermions which have many intrinsic properties like mass, spin, charge, symmetry and so on called quantum numbers and all these properties must be conserved[6] [7]. Quarks must possess another quantum number, which is color with three degrees of freedom (red, blue, and green). Quarks are interacting with each other through a massless field called gluon, and the dynamics of the quark and gluon system are called Quantum chromodynamics (QCD) [8]. Scientists have come up with quark confinement idea, which is the phenomenon that keeps quarks together inside a nucleon and continually emits gluons[3]. The photons are produced from the variables mechanisms such that thermal photons, prompt photons, and jet-medium photons. Also photons are emitted through the quark-gluon plasma phase (QGP), the phase of hadron gas due to jets, and by decay of resonances with long-lived into real photons [9].

Theory

The photons are emission from interaction quarks with gluons gives

$$E_\gamma \frac{dN_\gamma}{d^4x\, d^3E} = -\frac{f_g(E)}{8\pi^3} \mathrm{Im}\prod{}_i^f (E,P) \cdots\cdots\cdots\cdots (1)$$

by Where $f_g(E)$ is Boson distribution of gluons, $\mathrm{Im}\prod{}_i^f (E,P)$ is the propagation self-energy of photons. The propagation self-energy $\mathrm{Im}\prod{}_i^f (E,P)$ for photons emission from interaction quarks with gluons is [11].

$$\text{Im}\prod_{i}^{f}(E,P) = \left(\frac{N}{\pi^4} C_{ca}\right) g_E^2\, g_p^2\, \frac{T}{E_\gamma^2} \int_0^\infty |I_{tl}|[F_a(P) - F_q(E+P)]\ [P^2 + (PE)^2]dp \ldots\ldots\ldots \quad (2)$$

Where N is degeneracy factor, C_{ca} is casimir factor, g_e is electrodynamic strength, g_α is strength coupling of quantum chromodynamic constant, I_{tl} is integral of self- energy, F_a is the jutiner distribution of quarks in range P and P+E respectively.

The strength of electrodynamics' is [12] .

$$g_E^2 = 4\pi\alpha_E \cdots\cdots\cdots\cdots (3)$$

The quantum chromo dynamic coupling is to be wrote as [13].

$$g_p^2 = 4\pi\alpha_p \cdots\cdots\cdots\cdots (4)$$

The casimir factor is given by [14]

$$C_{ca} = \frac{N_c^2 - 1}{2N_c} \cdots\cdots\cdots\cdots (5)$$

Where N_c is the number of color of quarks $N_c = 3$, Inserting Eq 3),4) and 5) in Eq 2) and introduce the total electric charge for quarks in system $\Sigma_q\left(\frac{e_q}{e}\right)^2$ reduced to

$$\text{Im}\prod_{i}^{f}(E,P) = \left(\frac{N}{\pi^4}\right)\left(\frac{8}{6}\right) 16\pi^2\, \alpha_E\, \alpha_p \frac{T}{E_\gamma^2} \Sigma_q \left(\frac{e_q}{e}\right)^2 \int_0^\infty |I_{tl}|\big[F_a(P) - F_q\ (E+P)\big]$$

$$[P^2 + (P+E)^2]\text{dp} \cdots\cdots\cdots\cdots (6)$$

The integral self-energy is [15]

$$|I_{tl}| = |I_t - I_l| \cdots\cdots\cdots\cdots (7)$$

Where I_t and I_l are dimensionless constant, the Eq6) with Eq 7) reduced to

$$\text{Im}\prod_{i}^{f}(E,P) = \left(\frac{64N}{3\pi^2}\right) \alpha_E\, \alpha_p \frac{T}{E_\gamma^2} |I_t - I_l| \Sigma_q \left(\frac{e_q}{e}\right)^2 \int_0^\infty \big[F_a(P) - F_q\ (E+P)\big]$$

$$[P^2 + (P+E)^2]\text{dp} \cdots\cdots\cdots\cdots (8)$$

The juttner distribution function for quarks is[16].

$$F_a(P) = \frac{\lambda_Q}{e^{\frac{P}{T}} + \lambda_Q} \cdots\cdots\cdots\cdots (9)$$

And

$$F_q\ (E+P) = \frac{\lambda_Q}{e^{\frac{(P+E)}{T}} + \lambda_Q} \cdots\cdots\cdots\cdots (10)$$

Where λ_Q is the fugacity function of quark, Substituting Eq9),10) in Eq8) and simplify reduced to

$$\mathrm{Im}\prod{}_i^f(E,P) = \left(\frac{64N}{3\pi^2}\right)\alpha_E\,\alpha_p\,\frac{T}{E_\gamma^2}\sum_q\left(\frac{e_q}{e}\right)^2|I_t\text{-}I_l|\left[\int_0^\infty\frac{\lambda_Q(2P^2+2PE+E^2)}{e^{\frac{P}{T}}+\lambda_Q}dP-\int_0^\infty\frac{\lambda_Q(2P^2+2PE+E^2)}{e^{\frac{(P+E)}{T}}+\lambda_Q}dP\right]\cdots\cdots\cdots(11)$$

The solve of the integral term is

$$\int_0^\infty\frac{\lambda_Q(2P^2+2PE+E^2)}{e^{\frac{P}{T}}+\lambda_Q}dP-\int_0^\infty\frac{\lambda_Q(2P^2+2PE+E^2)}{e^{\frac{(P+E)}{T}}+\lambda_Q}dP=\lambda_Q T\,[2T^2\,\Gamma(3)+2ET\,\Gamma(2)+E^2\Gamma(1)]-\lambda_Q Te^{-\frac{E_\gamma}{T}}\,[T^2\Gamma(3)+2ET\,\Gamma(2)+E^2\Gamma(1)]\cdots(12)$$

Inserting Eq(12) in Eq(11) and simplify reduced to

$$\mathrm{Im}\prod{}_i^f(E,P)=\left(\frac{64N}{3\pi^2}\right)\alpha_E\alpha_p\,\frac{T}{E_\gamma^2}\sum_q\left(\frac{e_q}{e}\right)^2|I_t-I_l|(2T^2\Gamma(3)+2ET\,\Gamma(2)+E^2\Gamma(1)\left[\lambda_Q T-\lambda_Q Te^{-\frac{E_\gamma}{T}}\right]\cdots\cdots\cdots(13)$$

Inserting Eq(13) in Eq(1) and simplify reduced to

$$E_\gamma\frac{dN_\gamma}{d^4x\,d^3E}=-\frac{f_g(E)}{8\pi^3}\left(\frac{64N}{3\pi^2}\right)\alpha_E\alpha_p\,\frac{T}{E_\gamma^2}\sum_q\left(\frac{e_q}{e}\right)^2|I_t-I_l|\,\lambda_Q T\left(1-e^{-\frac{E_\gamma}{T}}\right)(2T^2\Gamma(3)+2ET\,\Gamma(2)+E^2\Gamma(1))\cdots\cdots\cdots(14)$$

The distribution of gluons $f_g(E)$ for $E_\gamma \gg T$ is [17].

$$f_g(E)=\frac{\lambda_G}{e^{\frac{E}{T}}-\lambda_G}=\frac{1}{\frac{e^{\frac{E}{T}}}{\lambda_G}-1}\approx\lambda_G e^{-\frac{E_\gamma}{T}}\cdots\cdots\cdots\cdots(15)$$

Where λ_G is fugacity of gluons, Inserting Eq(15) in Eq(14) and simplify reduced to

$$E_\gamma\frac{dN_\gamma}{d^4x\,d^3E}=\left(\frac{8N}{3\pi^5}\right)\alpha_E\alpha_p\frac{T^2}{E_\gamma^2}\sum_q\left(\frac{e_q}{e}\right)^2|I_t-I_l|\,\lambda_Q\lambda_G e^{-\frac{E_\gamma}{T}}\left(e^{-\frac{E_\gamma}{T}}-1\right)(2T^2\Gamma(3)+2ET\,\Gamma(2)+E^2\Gamma(1))\cdots\cdots\cdots(16)$$

For $E_\gamma \geq T$ then

$$e^{-\frac{E_\gamma}{T}}-1\approx e^{-\frac{E_\gamma}{T}}\cdots\cdots\cdots\cdots(17)$$

Inserting of Eq17) in Eq(16) and assume the degeneracy is equal to color number $N \approx 3$ reduced to

$$E_\gamma \frac{dN_\gamma}{d^4x\, d^3 E} = \frac{8}{\pi^5}\ \alpha_E \alpha_p \frac{T^2}{E_\gamma^2} \sum_q \left(\frac{e_q}{e}\right)^2 |I_t - I_l|\, ʎ_Q ʎ_G e^{-\frac{2E_\gamma}{T}} (2T^2\Gamma(3) +\ 2ET\ \Gamma(2) + E^2\Gamma(1)) \cdots\cdots\cdots (18)$$

The strength coupling is given by [18].

$$\alpha_p = \frac{6\pi}{(33-2N_f)\ln\frac{8T}{T_C}} \cdots\cdots\cdots (19)$$

Where T is the temperature of system, T_C is the critical temperature and N_f is the flavor number.

The critical temperature is given by [19].

$$T_C = \left[\frac{90B}{\pi^2(N_S \times N_C) + \frac{7}{4}(n_c \times n_s \times n_f)}\right]^{1/4} \cdots\cdots\cdots (20)$$

Where $B^{1/4}$ is the Bag constant.

Result and Discussion

The rate of photons produced in quark-gluon interaction at high energies creating in relativistic heavy ions collisions (RHIC) has been studied and evaluated theoretically. The rate of photons was presented for interaction $cg \rightarrow s\gamma$ system based on quantum chromodynamics theory and quantum consideration. The flavor number is the major parameter in limit $(1 \leq N_f \leq 6)$ it is calculated by taking the summation of flavor number $N_{f_i} = \sum_{i=1}^{6} N_{f_i}$, charm quark has ($N_f$ = 4) and strange quark have (N_f = 3) and N_f for $cg \rightarrow s\gamma$ system is N_f = (4+3)=7. The critical temperature is evaluated using Eq (21) with $B^{1/4}$ =0.225, 0.250GeV and the degrees of freedom for gluon are $N_S = 2$, $N_C = 8$ and the degrees of freedom for quarks are n_c = 3, n_s = 2, n_f = 7.The result of critical temperatures shown in Table.1.

Table 1.
Critical temperature calculation result for $cg \rightarrow s\gamma$ system.

$B^{1/4}$ (GeV)	T_C (GeV)
0.225	0.1271195803
0.250	0.1412439781

The strength coupling is calculated by Eq (20) with T_C in table1and system temperature in limit(185-305MeV) and n_f = 7. The result of strength coupling list in Table 2.

Table 2. The result of strength coupling for $cg \rightarrow s\gamma$ system.

T (GeV)	Coupling strength α	
	T_C = 0.1271195803GeV	T_C = 0.1412439781GeV
0.185	0.4041611441	0.4222867433
0.205	0.3879376106	0.4046072383
0.225	0.3743120864	0.3898079174
0.245	0.3626598242	0.3771871856
0.265	0.3525467943	0.3662599225
0.285	0.343661158	0.3566789801
0.305	0.3357725118	0.3981889561

The summation of squared electric charge of quark system is compute from $\left(\frac{e_q}{e}\right)^2 = \Sigma_{i=1}^{6}\left(\frac{e_q}{e}\right)^2$ with e_c = +3/2e and e_s = -1/3e and it is equal for $cg \rightarrow s\gamma$ system $^5/_9$e. the rate of photons emission is calculated by Eq(19) and MATLAP program with T_c from Table 1, $\propto_P$ from Table 2, $\propto_E = \frac{1}{137}$, I_t = 4.45, I_l =-4.26 [20], fugacity of charm and gluon respectively λ_Q = 0.068, λ_G = 1[21] and photon energy in rang (1-3.5GeV) result is shown in table 3 and Table4 and Figure 1and Figure 2.

Table 3. Rate of emission photons $R^H_{qg}(E,P)$
at T_C = 0.1271195803GeV for $\rightarrow s\gamma$ system with n_f =7 and λ_Q =0.068, λ_g = 1

E_γ (GeV)	$R^H_{qg}(E,P)\frac{1}{GeV^2fm^4}$						
	T=185 MeV	T=205 MeV	T=225MeV	T=245MeV	T=265MeV	T=285MeV	T=305MeV
	α_{QCD} = 0.4042	α_{QCD} = 0.3879	α_{QCD} = 0.3743	α_{QCD} = 0.3627	α_{QCD} = 0.3525	α_{QCD} = 0.3437	α_{QCD} = 0.3358
1	2.6411E-11	9.3596E-11	2.7116E-10	6.7378E-10	1.4852E-09	2.9758E-09	5.5184E-09
1.25	1.6253E-12	7.4285E-12	2.6488E-11	7.8207E-11	1.9935E-10	4.5210E-10	9.3284E-10
1.5	1.0294E-13	6.0858E-13	2.6785E-12	9.4227E-12	2.7846E-11	7.1659E-11	1.6491E-10
1.75	6.6287E-15	5.0778E-14	2.7633E-13	1.1602E-12	3.9816E-12	1.1645E-11	2.9933E-11
2	4.3123E-16	4.2853E-15	2.8867E-14	1.4481E-13	5.7776E-13	1.9225E-12	5.5255E-12
2.25	2.8245E-17	3.6440E-16	3.0409E-15	1.8240E-14	8.4666E-14	3.2075E-13	1.0316E-12
2.5	1.8588E-18	3.1151E-17	3.2220E-16	2.3121E-15	1.2493E-14	5.3914E-14	1.9412E-13
2.75	1.2275E-19	2.6731E-18	3.4283E-17	2.9444E-16	1.8526E-15	9.1110E-15	3.6739E-14
3	8.1264E-21	2.3004E-19	3.6593E-18	3.7625E-17	2.7576E-16	1.5459E-15	6.9836E-15
3.25	5.3905E-22	1.9839E-20	3.9152E-19	4.8205E-18	4.1163E-17	2.6311E-16	1.3319E-15
3.5	3.5811E-23	1.7139E-21	4.1970E-20	6.1887E-19	6.1582E-18	4.4888E-17	2.5467E-16

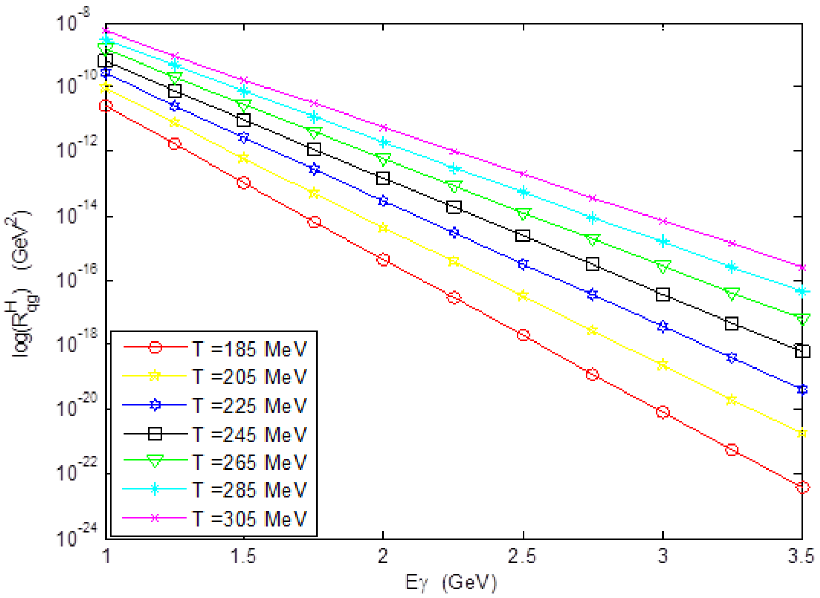

Figure 1. Rate of emission photons $R^{H}_{qg}(E,P)$ as function of E_γ at T_c= 0.1271195803GeV for $cg \rightarrow s\gamma$ system.

Table 4. Rate of emission photons $R^{H}_{qg}(E,P)$ at T_c= 0.1412439781GeV for $cg \rightarrow s\gamma$ system with N_f =7 and λ_Q =0.068, λ_Q = 1

E_γ (GeV)	$R^H_{qg}(E,P)\frac{1}{GeV^2fm^4}$						
	T=185 MeV	T=205 MeV	T=225 MeV	T=245 MeV	T=265 MeV	T=285 MeV	T=305 MeV
	α_{QCD} = 0.4042	α_{QCD} = 0.4042	α_{QCD} = 0.4042	α_{QCD} = 0.4042	α_{QCD} = 0.4042	α_{QCD} = 0.4042	α_{QCD} = 0.4042
1	2.7595E-11	9.7618E-11	2.8238E-10	7.0077E-10	1.5430E-09	3.0885E-09	6.5442E-09
1.25	1.6982E-12	7.7477E-12	2.7585E-11	8.1340E-11	2.0710E-10	4.6922E-10	1.1062E-09
1.5	1.0756E-13	6.3473E-13	2.7894E-12	9.8002E-12	2.8930E-11	7.4374E-11	1.9556E-10
1.75	6.9259E-15	5.2960E-14	2.8777E-13	1.2067E-12	4.1365E-12	1.2086E-11	3.5497E-11
2	4.5057E-16	4.4694E-15	3.0062E-14	1.5061E-13	6.0024E-13	1.9953E-12	6.5526E-12
2.25	2.9512E-17	3.8006E-16	3.1668E-15	1.8971E-14	8.7960E-14	3.3290E-13	1.2233E-12
2.5	1.9422E-18	3.2489E-17	3.3554E-16	2.4048E-15	1.2979E-14	5.5956E-14	2.3020E-13
2.75	1.2825E-19	2.7880E-18	3.5703E-17	3.0624E-16	1.9247E-15	9.4561E-15	4.3569E-14
3	8.4908E-21	2.3992E-19	3.8108E-18	3.9132E-17	2.8648E-16	1.6044E-15	8.2818E-15
3.25	5.6322E-22	2.0692E-20	4.0773E-19	5.0136E-18	4.2764E-17	2.7307E-16	1.5794E-15
3.5	3.7417E-23	1.7876E-21	4.3707E-20	6.4366E-19	6.3977E-18	4.6589E-17	3.0200E-16

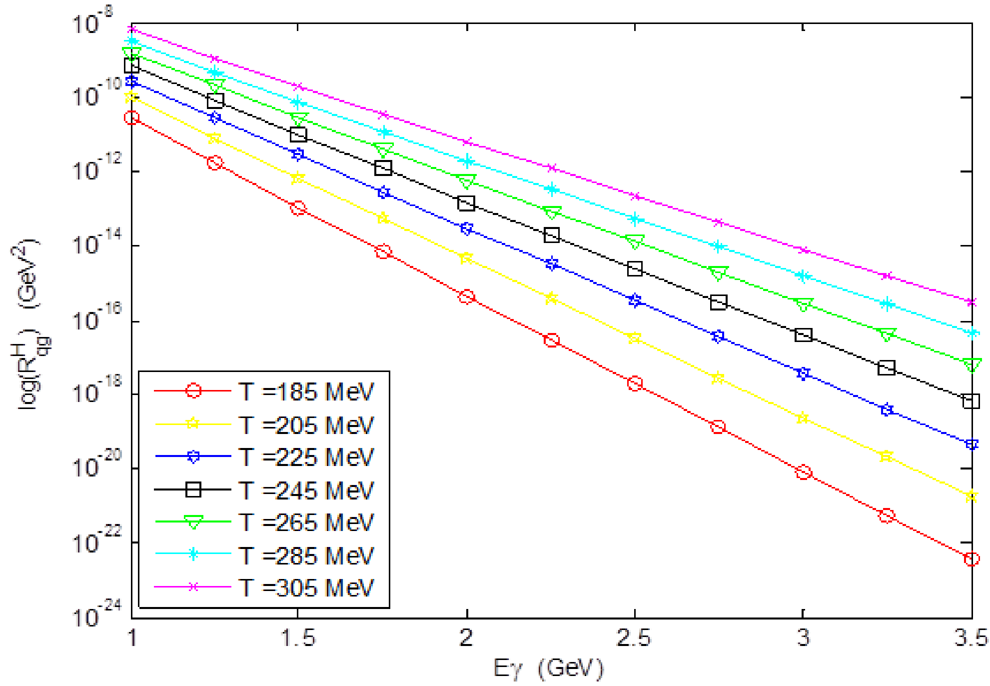

Figure 2. Rate of emission photons $R^H_{qg}(E,P)$ as function of E_γ at T_c= 0.1412439781GeV for $cg \rightarrow s\gamma$ system.

Discussion

The rate of photons emission $R^H_{qg}(E,P)$ in Eq (19) is related to energy of photons E_γ and coupling strength and it is effected by the critical temperature T_c, system temperature T and flavor number N_f of charm-gluon interaction. In Table 2, the coupling strength is calculated with the N_f =7 and various critical temperatures and the system temperatures in Eq (20). It is found that the coupling strength is proportional inversely with the system temperature where we note that the coupling strength decreases with increasing the system temperature from 185MeV to 305MeV. On the other side, the coupling strength of charm and gluon is function of critical temperature and it can be observed increase coupling strength with increasing the critical temperature from 0.1271195803GeV to 0.1412439781GeV. The rate of photons emission $R^H_{qg}(E,P)$ is calculated in Eq(19) with the system temperature in limit (185MeV≤T≤305MeV) and the energy of photons (1GeV≤ E_γ ≤3.5GeV) ,the critical temperature is calculated in Eq(21) T_c= 0.1271195803GeV, T_c= 0.1412439781GeV , the result of $R^H_{qg}(E,P)$ was shown in Table 3 and Table 4 with Figure 1 and Figure 2. We can observe from Table 3 that the maximum value of photons rate $R^H_{qg}(E,P)$= 5.5184E-09 $\frac{1}{GeV^2 fm^4}$ at T= 305MeV, α_p= 0.3358 and E_γ= 1GeV and the minimum value of photons emission rate is $R^{H}_{qg}(E,P)$= 3.5811E-23$\frac{1}{\mathrm{GeV^2 fm^4}}$ at T= 185MeV, α_p= 0.4042 and $\mathbf{E}_\gamma$=3.5GeV. Similarly the result of Table 4 is shown that the maximum value of photons emission rate $R^{H}_{qg}(E,P)$ = 6.5442E-09$\frac{1}{\mathrm{GeV^2 fm^4}}$ at T=305MeV, α_p= 0.3982 and E_γ = 1GeV and the minimum value of photons rate is $R^{H}_{qg}(E,P)$= 3.7417E-23$\frac{1}{\mathrm{GeV^2 fm^4}}$ at T=185MeV, α_p= 0.4223 and $\mathbf{E}_\gamma$=3.5GeV. if we compered between the calculation values of Table 1 and Table 2 we can found that the rate of photons emission for two tables increase with increasing of the system temperature from 185MeV to 305MeV and in contrast, the rate of photons emission of table 1 with T_c= 0.1271195803GeV is less than the rate of photons emission of table 2 with T_c= 0.1412439781GeV that mean the rate of photons emission increases with increasing the critical temperature. It is observed from Figure 1 and Figure 2 the relationship between the rate of photons emission $R^{H}_{qg}(E,P)$ and the energy of photons $\mathbf{E}_\gamma$. We can note the decreasing of the photons rate with increasing of the energy of photons from 1GeV to 3.5GeV at various values of critical temperatures and the system temperatures and N_f=7 and at $\mathbf{E}_\gamma$ =3.5GeV we can obtain the maximum values of the rate of emission photons in the both of critical temperatures.

Conclusion

In conclusion, the rate of emission photons from the interaction of charm with gluon depending on the coupling strength, critical temperature, the temperature of system, the energy of photon. Therefore, the critical temperature and the coupling strength have a pure effect on the emitted photons yield at high temperature of system (185-305MeV). The rate of photon emission for quark-gluon interaction is inversely proportional to the coupling strength and directly proportional to critical temperature and the system temperature for $cg \rightarrow s\gamma$ system with flavor number N_f=7. In addition the emitted photons products is related to the photon energy which be the maximum at E_γ=1GeV. In conclusion the photon emission is produced forcedly at less coupling strength and high temperature T= 305MeV, T_c= 0.1412439781GeV and E_γ=1GeV.

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