Calculation of the Rate of Photons Emission from Charm-Gluon Interaction

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ABSTRACT

In this research, the rate of photons emission from quark-gluon interaction based on the quantum chromodynamics theory was calculated. The rate of photons emission was evaluated for $cg \rightarrow dy$ system due to essential parameters, include the strength coupling constant, system temperature and critical temperature. The photons emission from charm interaction with gluon affected strongly with increasing or decreasing of the coupling strength. The effect of critical temperature on the rate of photons emission which is small at critical temperature $T_c =0.160291913\text{GeV}$ when compared with the rate of photons emission at $T_c=0.1894358972\text{GeV}$ was investigated. The effect of the energy of system in the limit of $1\leq E_y \leq 3.5\text{GeV}$ on the photons emission rate was discussed and, we found that it decrease with increase of the photon energy. On the contrary, the rate of emission photon was increased with increasing of system temperature from 185 to 305MeV.

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خليصة

حساب معدل انبعاث الفوتونات من تفاعل الساحر-الجلون

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الكلمات المفتاحية:
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في هذا البحث، نحسب معدل انبعاث الفوتونات من تفاعل كوارك-جبلون اعتداما على نظرية الديناميكية الكونية. معدل انبعاث الفوتونات قدر من نظام $cg \rightarrow dy$ بسبب معلمات أساسية ، تشمل ثابت اقتران القوة ، درجة حرارة النظام ، درجة الحرارة الحالة. انبعاث الفوتونات من تفاعل الكوارك الساحر مع الجلون يتأثر بقوة مع زيادة أو نقصان قوة الاقتران . تحققنا في تأثير درجة الحرارة الحالة على معدل انبعاث الفوتونات والذي يكون صغير عند درجة الحرارة $T_c =0.160291913\text{GeV}$ مقارنة مع معدل انبعاث الفوتونات.
1. INTRODUCTION

Elementary particles physics is one of the most important branches of physics [1]. Elementary particles are defined as the particles do not broken up into smaller pieces [2]. It is classified according to standard model into fermions and bosons [3]. The basic component of matter is the quark, which is a hypothetical particle hypothesized by the two scientists George Zweig and Gell-Mann [4]. There are six quarks increasing in mass, distributed over three generations, in addition to the antiquarks, all these quarks interacted with fundamental forces and the only one who interacted with the strong force through the exchange of gluons [5]. The color charge is property of quark and gluon and through which strong interactions take place. There are three kind of color charge red, blue, and green. The rule that allows quarks to combine to form hadrons is that they are color neutral. There are eight gluons which represent a pair of colors and anti-colors [6][7]. The theory that depicts the strong interactions is quantum chromodynamics theory (QCD) [8]. Charm (C) is a quark flavor was invented to explain the big narrowness of the huge resonances ($\psi$) during observation of meson $J/\psi$ resonance produced by electron and antielectron annihilation [9]. Photon is a massless elementary particle in the form of electromagnetic radiation. Photons are produced in heavy ions collisions by establishing the quark-gluon matter system and exploring the state of matter in decoupled quarks and gluons. The two phenomena that predict the behavior of quarks at high temperature and high density are confinement and deconfinement [10][11]. Direct photons can be produced in the

quark-gluon plasma phase through interactions $q + q \rightarrow g + \gamma$ or $q + g \rightarrow q + \gamma$ while in the hadron gas phase, bremsstrahlung photons can be produced through the scattering of mesons or baryons[12], and they can also be produced in the quark-gluon plasma phase through the elastic scattering of a quark - quark or a quark - gluon. But it is dominated by direct photon production interactions, and the condition for the emission of bremsstrahlung photons is the availability of a particle with an electric charge [13].

2. THEORY

The photons emission from quark-gluon interaction given by [14].

$$R_{q\bar{q}}^H(E, P)=\frac{1}{8\pi^3} F_G(E) \text{Im} \prod_{i=1}^{f} (E, P) \cdots \cdots \cdots (1)$$

Where $F_G(E)$ is distribution function of gluons which is given by [15].

$$F_G(E)=\frac{1}{e^{E/\lambda_G}-1} \cdots \cdots \cdots (2)$$

Where $\lambda_G$ is fugacity of gluons, the propagation of self-energy $\text{Im} \prod_{i}^{f} (E, P)$ for photons emission from the interaction of quarks with gluons is [16]

$$\text{Im} \prod_{i}^{f} (E, P) = (\frac{N}{\pi^2} C_{ca}) \ g^2 \ g_c^2 \ \frac{T}{E^2} \ \int_0^\infty |I_t| [F_a (P) - F_q (E + P)] \ [P^2 + (P + E)^2] \ dp \ \cdots (3)$$

Where $N$ is degeneracy factor $N \approx 3$, $C_{ca}$ is casimir factor which is given by[17]

$$C_{ca} = \frac{N_c^2 - 1}{2N_c} \ \cdots \cdots \cdots (4)$$

Where $N_c$ is the number of quarks $N_c = 3$, inserting Eq(4) in Eq (3) and substitute the
value of degeneracy facture and the number of quarks and simply reduced to

\[ \text{Im} \Pi_i^{(E,P)} = \frac{4}{\pi^2} g_E^2 E \frac{T}{E^2} \int_{0}^{\infty} |l_\alpha| \left( F_\alpha (P) - F_q (E + P) \right) \left( P^2 + 2EP + E^2 \right) dP \cdots (5) \]

The strength of electrodynamics is [18].

\[ g_E^2 = 4\pi\alpha_E \cdots \cdots \cdots (6) \]

The quantum chromodynamics coupling is [19].

\[ g_c^2 = 4\pi\alpha_c \cdots \cdots \cdots (7) \]

The integral self-energy is [20]

\[ |l_\alpha| = |l_t - l_l| \cdots \cdots \cdots (8) \]

Where \( l_t \) and \( l_l \) are dimensionless constant, inserting the Eq(6),(7),(8) in Eq (5) and introduce the total electric charge for quarks in system \( \sum q e^2 \), Eq (5) is reduced to

\[ \text{Im} \Pi_i^{(E,P)} = \frac{64}{\pi^2} \alpha_E \alpha_c \frac{T}{E^2} |l_t - l_l| \sum q e^2 \int_0^{\infty} \left( F_\alpha (P) - F_q (E + P) \right) \left( P^2 + 2EP + E^2 \right) dP \cdots (9) \]

The juttner distribution function for quarks is [21]

\[ F_\alpha (P) = \frac{\lambda_Q}{e^{P/T} + \lambda_Q} \cdots \cdots \cdots (10) \]

And

\[ F_q (E + P) = \frac{\lambda_Q}{e^{(P+E)/T} + \lambda_Q} \cdots \cdots \cdots (11) \]

Where \( \lambda_Q \) is the fugacity function of quark, inserting Eq(10),(11) in Eq(9) which reduced it to

\[ \text{Im} \Pi_i^{(E,P)} = \frac{64}{\pi^2} \alpha_E \alpha_c \frac{T}{E^2} |l_t - l_l| \sum q e^2 \int_0^{\infty} \frac{\lambda_Q}{e^{P/T} + \lambda_Q} \left( 2P^2 + 2PE + E^2 \right) dP \cdots (12) \]

The solve of the integral term is

\[ \int_0^\infty \frac{\lambda_Q}{e^{P/T} + \lambda_Q} \left( 2P^2 + 2PE + E^2 \right) dP = \frac{\lambda_Q T - \lambda_Q T e^{-E/T} \left( 2T^2 \Gamma(3) + 2ET \Gamma(2) + E^2 \Gamma(1) \right)}{\left( 33 - 2N_f \right) \ln^{N_f} T_c} \cdots \cdots \cdots (13) \]

Inserting Eq(13) in Eq(12) and simply reduced to

\[ \text{Im} \Pi_i^{(E,P)} = \frac{64}{\pi^2} \alpha_E \alpha_c \frac{T}{E^2} |l_t - l_l| \sum q e^2 \int_0^{\infty} \left[ (1 - e^{-E/T}) \left( 2T^2 \Gamma(3) + 2ET \Gamma(2) + E^2 \Gamma(1) \right) \right. \cdots (14) \]

At \( E \gg T \), the distribution of gluons in Eq(2) reduced to

\[ F_G (E) = \frac{1}{8\pi^2} \frac{64}{\pi^2} \alpha_E \alpha_c \frac{T^2}{E^2} |l_t - l_l| \sum q e^2 \lambda_Q \lambda_G e^{-E/T} (1 - e^{-E/T}) \left( 2T^2 \Gamma(3) + 2ET \Gamma(2) + E^2 \Gamma(1) \right) \cdots (15) \]

Inserting Eq (15) , (14) in Eq (1) can be reduced to

\[ R_{qg}^H (E,P) = \frac{1}{8\pi^2} \alpha_E \alpha_c \frac{T^2}{E^2} |l_t - l_l| \sum q e^2 \lambda_Q \lambda_G e^{-E/T} (e^{-E/T} - 1) \left( 2T^2 \Gamma(3) + 2ET \Gamma(2) + E^2 \Gamma(1) \right) \cdots (17) \]

And by multiplying Eq(16) by \(-1\) and simply reduced to

\[ R_{qg}^H (E,P) = \frac{8}{\pi^2} \alpha_E \alpha_c \frac{T^2}{E^2} |l_t - l_l| \sum q e^2 \lambda_Q \lambda_G e^{-2E/T} \left( 2T^2 \Gamma(3) + 2ET \Gamma(2) + E^2 \Gamma(1) \right) \cdots (18) \]

For \( E \gg T \), \( e^{-E/T} \rightarrow 1 \)

Then Eq(18) together with Eq(17) reduced to

\[ R_{qg}^H (E,P) = \frac{8}{\pi^2} \alpha_E \alpha_c \frac{T^2}{E^2} |l_t - l_l| \sum q e^2 \lambda_Q \lambda_G e^{-2E/T} \left( 2T^2 \Gamma(3) + 2ET \Gamma(2) + E^2 \Gamma(1) \right) \cdots (19) \]

The strength coupling is given by [22].

\[ \alpha_c = \frac{6\pi}{(33 - 2N_f) \ln^{N_f} T_c} \cdots \cdots \cdots (20) \]

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 [23].
where $B^{1/4}$ is the Bag constant.

3. RESULT AND DISCUSSION

The rate of photons produced in quark-gluon interaction at high energies created in relativistic heavy ions collisions (RHIC) was studied and evaluated theoretically. We estimated the critical temperature according to the Bag constant in Eq(21) with $B^{1/4} = 0.275, 0.325 \text{GeV}$ and the degrees of freedom for gluon are $N_g = 2, N_c = 8$ and the degrees of freedom for quarks are $n_c = 3, n_s = 2, n_f = 6$. The results of critical temperatures can be shown in Table 1.

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

<table>
<thead>
<tr>
<th>$B^{1/4}$ (GeV)</th>
<th>$T_c$ (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.275</td>
<td>0.160291913</td>
</tr>
<tr>
<td>0.325</td>
<td>0.1894358972</td>
</tr>
</tbody>
</table>

The strength coupling between charm quarks with gluon was calculated using Eq(20) with $T_c$ in Table 1, and system temperature in limit(185-305MeV) and $N_f = 6$. The result of strength coupling is listed in Table 2.

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

<table>
<thead>
<tr>
<th>$T$ (GeV)</th>
<th>Coupling strength $\alpha_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_c = 0.160291913$</td>
</tr>
<tr>
<td></td>
<td>$T_c = 0.1894358972$</td>
</tr>
<tr>
<td>0.185</td>
<td>0.4038139262</td>
</tr>
<tr>
<td>0.205</td>
<td>0.3859880906</td>
</tr>
<tr>
<td>0.225</td>
<td>0.371131311</td>
</tr>
<tr>
<td>0.245</td>
<td>0.358508117</td>
</tr>
<tr>
<td>0.265</td>
<td>0.347613149</td>
</tr>
<tr>
<td>0.285</td>
<td>0.329665114</td>
</tr>
<tr>
<td>0.305</td>
<td>0.329665114</td>
</tr>
</tbody>
</table>

The rate of photons emission was calculated by summation of the electric charge $\frac{\sum q(E^2)}{e^2}$ for $cg \rightarrow d\gamma$ system with $e_c = +3/2e$ and $e_d = -1/3e$ and results was $5/9e$. The flavor number $N_f = 6$ for the system, it was calculated from the summation of $N_f = \sum_{i=1}^{6} N_{f_i}$ for charm and down quarks and with inserting $\alpha_g = 1/137$ and the self-integral constant $I_c = 4.45, I_f = 4.26$ [24], supposing that the fugacity $\lambda_Q = 0.068, \lambda_c = 1$[25] in Eq(19) with taking the values of critical temperature from Table 1, and the values of strength coupling from Table 2 with photon energy in rang (1-3.5GeV). The resulted data are given in Table (3),(4) with Figures(1),(2).

**Table 3. Rate of emission photons $R_{qg}^H (E, P)$ at $T_c=0.160291913$GeV for $cg \rightarrow d\gamma$ system with $N_f = 6$ and $\lambda_Q = 0.068, \lambda_g = 1$.**

<table>
<thead>
<tr>
<th>$E_y$ (GeV)</th>
<th>$\alpha_{QCD} = 0.4038$</th>
<th>$\alpha_{QCD} = 0.3860$</th>
<th>$\alpha_{QCD} = 0.3711$</th>
<th>$\alpha_{QCD} = 0.3585$</th>
<th>$\alpha_{QCD} = 0.3476$</th>
<th>$\alpha_{QCD} = 0.3381$</th>
<th>$\alpha_{QCD} = 0.3297$</th>
</tr>
</thead>
<tbody>
<tr>
<td>T=185 MeV</td>
<td>2.6388E-11</td>
<td>9.3126E-11</td>
<td>2.6885E-10</td>
<td>6.6605E-10</td>
<td>1.4644E-09</td>
<td>2.9275E-09</td>
<td>5.4180E-09</td>
</tr>
<tr>
<td>T=205 MeV</td>
<td>1.6239E-12</td>
<td>7.3911E-12</td>
<td>2.6263E-11</td>
<td>7.7312E-11</td>
<td>1.9656E-10</td>
<td>4.4476E-10</td>
<td>9.1587E-10</td>
</tr>
<tr>
<td>T=265 MeV</td>
<td>4.3086E-16</td>
<td>4.2638E-15</td>
<td>2.8622E-14</td>
<td>1.4315E-13</td>
<td>5.6968E-13</td>
<td>1.8913E-12</td>
<td>5.4250E-12</td>
</tr>
</tbody>
</table>
Table 4. Rate of emission photons $R_{qg}^H(E, P)$ at $Tc=0.1894358972$GeV for $cg \rightarrow d \gamma$ system with $N_f = 6$ and $\gamma_Q = 0.068$, $\gamma_g = 1$

<table>
<thead>
<tr>
<th>$E_{\gamma}$ (GeV)</th>
<th>$R_{qg}^H(E, P)$</th>
<th>$1$ GeV$^2$fm$^4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T=185$ MeV</td>
<td>$\alpha_{QCD} = 0.4366$</td>
<td>$1.5657 \times 10^{-9}$</td>
</tr>
<tr>
<td>$T=205$ MeV</td>
<td>$\alpha_{QCD} = 0.4159$</td>
<td>$2.0183 \times 10^{-10}$</td>
</tr>
<tr>
<td>$T=225$ MeV</td>
<td>$\alpha_{QCD} = 0.3987$</td>
<td>$3.8429 \times 10^{-11}$</td>
</tr>
<tr>
<td>$T=245$ MeV</td>
<td>$\alpha_{QCD} = 0.3841$</td>
<td>$3.8429 \times 10^{-11}$</td>
</tr>
<tr>
<td>$T=265$ MeV</td>
<td>$\alpha_{QCD} = 0.3717$</td>
<td>$1.7249 \times 10^{-11}$</td>
</tr>
<tr>
<td>$T=285$ MeV</td>
<td>$\alpha_{QCD} = 0.3608$</td>
<td>$1.7249 \times 10^{-11}$</td>
</tr>
<tr>
<td>$T=305$ MeV</td>
<td>$\alpha_{QCD} = 0.3512$</td>
<td>$5.7796 \times 10^{-12}$</td>
</tr>
</tbody>
</table>

Figure 1. Rate of emission photons $R_{qg}^H(E, P)$ as function of $E_{\gamma}$ at $Tc=0.160291913$GeV for $cg \rightarrow d \gamma$ system.
The rate of photons emission was calculated and studied to understand the mechanism of quark system. The rate of photons emission \( R_{qg}^H(E,P) \) in Eq (19) is related to energy of photons \( E_\gamma \) and coupling strength \( \alpha_c \) which was affected by the critical temperature \( T_c \), system temperature \( T \) and flavor number \( N_f \) of charm-gluon interaction. From Table 2, the coupling strength was calculated with \( N_f=6 \) and various critical temperatures and the system temperatures in Eq (20). It can be found that the coupling strength decreases with increasing the system temperature from 185MeV to 305MeV. On the other side, the coupling strength of charm-gluon is function of critical temperature \( T_c \) and it can be observed increase coupling strength with increasing the critical temperature from 0.160291913GeV to 0.1894358972GeV. The rate of photons emission \( R_{qg}^H(E,P) \) was calculated via Eq(19) with the system temperature in the limit of \( (185 \text{MeV} \leq T \leq 305 \text{MeV}) \) and the energy of photons \( (1 \text{GeV} \leq E_\gamma \leq 3.5 \text{GeV}) \), the critical temperature was calculated using Eq(21) where the result of \( R_{qg}^H(E,P) \) can be seen in Table 3 and Table 4 with Figure 1 and Figure 2. We can observe that the maximum value of photons rate at \( T=305\text{MeV} \) and \( E_\gamma=1\text{GeV} \) where \( R_{qg}^H(E,P) = 5.4180E-09 \frac{1}{\text{GeV}^2\text{fm}^4} \) at \( \alpha_c = 0.3297 \) and \( T_c=0.160291913\text{GeV} \) and \( R_{qg}^H(E,P)=5.7722E-09 \frac{1}{\text{GeV}^2\text{fm}^4} \) at \( \alpha_c=0.3512 \) and \( T_c=0.1894358972\text{GeV} \). On the other hand the minimum value of photons emission rate at \( T=185\text{MeV} \) and \( E_\gamma=3.5\text{GeV} \) where \( R_{qg}^H(E,P) = 3.5780E-23 \frac{1}{\text{GeV}^2\text{fm}^4} \) at \( \alpha_c = 0.4038 \) and \( T_c=0.1894358972\text{GeV} \) and \( R_{qg}^H(E,P) = 3.8688E-23 \frac{1}{\text{GeV}^2\text{fm}^4} \) at \( \alpha_c = 0.4366 \) and
$T_c = 0.1894358972\text{GeV}$. If a comparison can be made between the calculation values of Table 1 and Table 2, one can find that the rate of photons emission for two tables increase with the increasing of the system temperature from 185MeV to 305MeV and in contrast, the rate of photons emission of Table 1 with $T_c = 0.160291913\text{GeV}$ is less than the rate of photons emission of Table 2 with $T_c = 0.1894358972\text{GeV}$ that mean the rate of photons emission increases with increasing the critical temperature. Figure 1 and Figure 2 demonstrate the relationship between the rate of photons emission $R_{H_\text{lg}}(E, P)$ and the energy of photons $E_\gamma$. 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 $N_f = 6$ and at $E_\gamma = 3.5\text{GeV}$ can be noticed.

4. CONCLUSION

In conclusion, the quantum chromodynamics theory can be considered to derive a hypothetical model to calculate the rate of emission of photons for $c g \rightarrow d \gamma$ system with flavor number $N_f = 6$. The rate of photon was calculated as a function of critical temperature, strength coupling, photon energy, thermal energy, electric charge and fugacity of quark and gluon using MATLAB program. It was found that the emitted photons that yield at high temperature of system (185-305MeV) for charm-gluon interaction is inversely proportional to the coupling strength and directly proportional to critical temperature and the system temperature for $c g \rightarrow d \gamma$ system. In addition the emitted photons yield is related to the photon energy, where it decreases with increasing of the photon energy for two critical temperature.

5. REFERENCES


