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Study of Photons Emission Rate of Quark-Antiquark at Higher Energy

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ABSTRACT

In this paper, the dynamic of quark and anti-quark interaction has been used to study the production of photons in the annihilation process based on the theory of chromodynamic. The rate of the photon is to be calculated for charm and anti-strange interaction $c\bar{s}\rightarrow\gamma g$ system with critical temperature $T_c = 113$ and 130 MeV and photon energy $1.5 \leq E_\gamma \leq 5$GeV/c. Here the critical temperature, strength coupling and photons energy are assumed to be affected dramatically on the rate of photons emission of state interaction $c\bar{s}$, which can form gluon possible structures and photon emission state. The decreased photons emission yields with increased strength couple of quarks reaction due to increase critical temperature from 113 MeV to 130 MeV were predicted. We can be found less difference in photons rate for the two different critical temperatures and strength coupling.

KEYWORDS: Photons emission, quark-antiquark and high energy.

INTRODUCTION

The existence of elementary particles is the most important prominent field of physical science. It is the fundamental of building the protons and neutrons in the nucleus and they are part of the Standard Model, the most successful grand model of fundamental physics [1]. In the 1960s, a variety of strongly interacting particles have been observed in nucleon experiments, there are named the hadrons by Okun later. Depending on these observations, both Gell-Mann M. and Zweig G. proposed independently the quark model [2]. The standard model is very important for elementary particle physics to achieve higher energies collision. This higher elegant theory describes how the quarks interact through fundamental interactions by which it is influenced [3] There are many scientific have been introduced using different theories to investigate and study the interaction of quark-gluon and construction the nature of nucleons structure [4]. The standard model encompasses all recognize elementary particles, provides a good discussion of an interaction between them. The Standard Model (SM) was succeed with unprecedented precision mainly because of using the perturbative methods of scattering theory [5]. In 2012, the standard model has been confirmed when the announcement the Compact Muon Solenoid (CMS) and Atlas research groups on their detected of the Higgs boson [6]. Shortly after quarks model many models are developed to describe the characteristic of hadrons. Greenberg was introduced the color hypothesis that describe the quarks are fermions have three color degree of freedom [7]. According to the color confinement phenomena, the quark is bounded into the color neutral hadrons by variety configurations. The baryon consists from three quarks with meson, it makes the pair of quark and anti-quark are the common hadronic matter, they observe in collision experiments [8]. The basic constituents of the nucleon is quarks and gluon. Both quarks and gluons are played key role in production nucleon mass. The spin of the nucleons is built up from the spin of quarks fermion has spin 1/2 and gluon is bosonic has spin-1 [9]. The BNL Relativistic Heavy Ion Collider (RHIC) and the CERN LHC are supplying more important information about interaction dynamics of quark-gluon system and enable us to understand in the framework of QCD theory depending on heavy hadrons experiments [10]. Photons produce in different collisions processes. There are different photons sources; thermal photons prompt photons, and photons are produced by hard interactions. There are created experimentally in heavy-ion collisions [11]. The states of quark and anti-quark have been produced in nuclear collisions. It studies and investigates for evidence of transition in nuclear matter, where quarks and gluons confine in hadron [12]. One of the evidences of the phase transfer between normal nuclear matter is the producing of quark and anti-quark in the laboratory collisions. It has been studied by many methods. Both quarks and gluons confine in hadrons matter and transfer to a plasma phase when the colored is deconfined [13]. In Figure 1, Feynman diagrams of photon produce mechanisms from, quark and anti-quark annihilation.

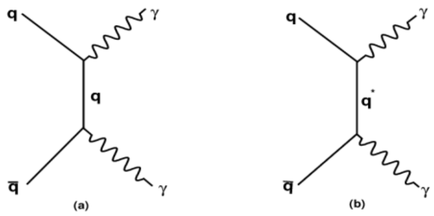

Figure 1. Feynman diagrams of photon production by quark and anti-quark annihilation [14].

Quantum chromodynamics theory (QCD) has been the fundamental of the strong interaction. In recent decades, the QCD theory become the topic of elementary particles research [15-16].

THEORY

The photons spectrum from quark anti quarks annihilation is given by [17].

$$R_\gamma = \frac{4{n_s}^2}{(2\pi)^6} F_q(p_\gamma) \iiint F_{\overline{q}}(p_{\overline{q}}) \qquad (1)$$

The Eq. 1 will be derived to obtain a mathematical formula by which the rate of photons can be calculated. Where n_s is number of quark spins,$F_q(p_\gamma)$ and $F_{\overline{g}}(p_{\overline{q}})$ are Juttner function for quark and gluon,$E_{\overline{q}}$ and E_γ are quark and photons energy,ds,$d\phi$ and $dE_{\overline{q}}$ are element of momentum, solid angle and quarks energies and $\sigma_{q\overline{q}}(s)$ is the total cross section of annihilation process$\sigma_{q\overline{q}}(s)$is [18].

$$\sigma_{q\overline{q}}(s) = \left(\frac{e_q}{e}\right)^2 \sigma_a(s) \qquad (2)$$

Where e_q and e are the quarks and electronic charges and $\sigma_a(s)$ is the effective cross section.
The distribution of quark is given by Juttner function [19].

$$\mathrm{F}_{\overline{q}}(E_{\overline{q}}) = \frac{\lambda_{\overline{q}}}{e^{\frac{E_{\overline{q}}}{T}} + 1} \qquad (3)$$

Where $\lambda_{\overline{q}}$is fugacity parameter of anti-quark. The Bose-Einstein distribution $F_B(E)$ for gluon is [20].

$$F_g(E_g) = \frac{\lambda_g}{e^{E_g/T} - 1} \qquad (4)$$

Inserting eqs. 2, 3 and 4 in eq. 1 and carry out the first integral over $E_{\overline{q}}$ under the condition taken $E_{\overline{q}} \geq \frac{s}{4E_\gamma}$ [21].

$$R_\gamma = \frac{4{n_s}^2}{(2\pi)^6} F_q(p_\gamma) \left(\frac{e_q}{e}\right)^2 \int \sigma_a(s)\sqrt{s(s-4m} + \frac{\lambda_{\overline{q}}}{e^{\frac{E_{\overline{q}}}{T}} + 1} \frac{\lambda_g}{e^{\frac{E_g}{T}} - 1}\Bigg] dE_{\overline{q}}\Bigg] \int_0^{2\pi} d\phi \qquad (5)$$

The solution of the second and third integral in eq. 5 for case $E_{\overline{q}} \cong E_g$give results

$$R_\gamma = \frac{4{n_s}^2}{(2\pi)^5} F_q(p_\gamma) \left(\frac{e_q}{e}\right)^2 \int \Bigg[T\lambda_{\overline{q}} \sum_{n=1}^{\infty} \frac{(-1)^{n+1}}{} + T\lambda_{\overline{q}}\lambda_g \sum_{n=1}^{\infty} \frac{1}{2n+1} e^{\frac{-(2n+1)s}{4E_\gamma T}} \Bigg] \sigma_a(s)\sqrt{s(s} \qquad (6)$$

But [22].

$$\sqrt{s(s-4m^2)}\sigma(s) = 4\pi\alpha_0\alpha_s m^2 \left[ln\left(\frac{s}{m^2}\right) - 1 \right] \qquad (7)$$

Inserting eq. 7 in eq. 6 with s > $4m^2$ to reduced

$$R_\gamma = \frac{4{n_s}^2}{(2\pi)^5} F_q(p_\gamma) \left(\frac{e_q}{e}\right)^2 4\pi\alpha_0\alpha_s m^2 T\lambda_{\overline{q}} \qquad (8)$$

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$$\int\left[\sum_{n=1}^{\infty}\frac{(-1)^{n+1}\left(e^{\frac{-s}{4E_\gamma T}}\right)^n}{n} + \lambda_g\sum_{n=1}^{\infty}\frac{1}{2n+1}e^{\frac{-(2n+1)s}{4E_\gamma T}}\right] ln\left(\frac{s}{m^2}\right) - 1\, ds$$

Under assume $s = 4m^2$z in eq. 8 and solution integral for $m^2 \ll E_\gamma T$with$\sum_{i=1}^{\infty}\frac{(-x)^k}{k!}$ For $(-x)^k = \left(\frac{-m^2}{E_\gamma T}\right)^k$ [22], to results

$$R_\gamma = \frac{4n_s{}^2}{(2\pi)^5}\frac{F_q(p_\gamma)}{4E_\gamma}\left(\frac{e_q}{e}\right)^2\frac{1}{4E_\gamma}4\pi\alpha_0\alpha_s T m^2 \quad (9)$$

But the power series reduced to [23].

$$\sum_{n=1}^{\infty}\frac{(-1)^{n+1}}{(2n+1)^2} = \left(1-\frac{1}{2^2}\right)\zeta(2)\,\frac{\pi^2}{6} \quad (10)$$

and

$$\sum_{n=1}^{\infty}\frac{(-1)^{n+1}}{n^2} = \frac{\pi^2}{6} \quad (11)$$

Subsuming eq. 10 and eq. 11 into eq. 9 at λ_g 1, we get

$$R_\gamma = \frac{4n_s{}^2}{(2\pi)^5}F_q(p_\gamma)\left(\frac{e_q}{e}\right)^2\pi\alpha_0\alpha_s T^2\lambda_{\bar{q}}\left(\frac{\pi^2}{6}\right)\left[ln - C - lnn - ln(2n+1) - 1\right] \quad (12)$$

The Juttner distribution function for quark in eq. 12 for $E_\gamma \gg T$ reduce to

$$F_q(p_\gamma) = \frac{\lambda_q}{e^{\frac{E_\gamma}{T}}+1} \approx \lambda_q e^{\frac{-E_\gamma}{T}} \quad (13)$$

Then inserting eq. 13 in eq. 12 with $n_s = 2$ to obtain.

$$R_\gamma = \frac{\alpha_0\alpha_s}{3(2\pi)^2}\left(\frac{e_q}{e}\right)^2 T^2\lambda_{\bar{q}}\lambda_q e^{\frac{-E_\gamma}{T}} \quad (14)$$

Where α_0 is the electrodynamic strength constant$\alpha_0 = \frac{e^2}{\hbar c} = (137)^{-1}$,$\alpha_s$ is the chromodynamic strength constant, $\lambda_{\bar{q}}$ and λ_q are the fugacity of quark and anti-quark and$m$ is the finite quark mass is write as [24].

$$m == \sqrt{4\pi\alpha_s}T \quad (15)$$

The eq. 21 with eq. 22 reduced to

$$R_\gamma = \frac{\alpha_0\alpha_s}{3(2\pi)^2}\left(\frac{e_q}{e}\right)^2 T^2\lambda_{\bar{q}}\lambda_q e^{\frac{-E_\gamma}{T}}\left[ln\left(\frac{4E_\gamma T}{m^2}\right) - C + 1 + lnn + ln(2n+1)\right] \quad (16)$$

The quantum chromo dynamic strength coupling is calculated using [11].

$$\alpha_s = \frac{6\pi}{(33-2n_f)ln\frac{8T}{T_c}} \quad (17)$$

The transition energy is [25].

$$T_c = \left(\frac{90B}{\pi^2 n_{gq}}\right)^{\frac{1}{4}} \quad (18)$$

Where B is the Bag constant, where this constant is used to explain the relationship between the critical temperature and degree of freedom for quark and gluon. In addition, $n_{gq} = n_g + \frac{7}{8}(n_q + n_{\bar{q}})$ is the number of gluonsn_g and quarks n_q and anti quarks $n_{\bar{q}}$ degrees of freedom.

RESULTS AND DISCUSSION

In this work, the photons emission rate is produced by the annihilation of charm anti-strange interaction using the quantum chromo dynamic theory model QCD. The photons rate parameters of critical temperature, strength coupling, the distribution function of quark and rate were calculated according to simple quantum mode, except the values of photons energy are taken from experimental literature. The Juttner distribution is used to estimate the distribution function of a charm quark and anti- strange quark and we use an inelastic cross-section at different critical temperatures 113 and 130 MeV respectively. The critical temperature can be evaluated using eq. 18 with taking the Bag constant $B^{1/4} = 200 \wedge 230$MeV. This constant is derived from mathematical model called bag model [25]. In addition, it was used number of degrees of freedom for gluon$n_g = n_s \times n_c = 16$where the spin and color states are$n_s = 2$and$n_c = 8$ and the degrees of freedom for quark$n_q = n_{\bar{q}} = n_c \times n_s \times n_f = 42$ where the number of quark color, spin and flavor are $n_c = 3, n_s = 2 \wedge n_f = 7$ respectively to results

$n_{gq} = 52.75$. The results of critical temperatures list in Table 1.

Table 1. Critical temperature results according to Bag mode for $c\overline{s}$ →γg system.

Bag constant $B^{1/4}MeV$	Critical temperature $T_c MeV$
200	113
230	130

To calculate the strength coupling, we must estimation the favor number for $c\overline{s}$→γg system using $\sum n_f = 7$. The coupling strength parameter is calculated using Eq. 17 with critical temperature in Table 1 and flavor number $\sum n_f = 7$for$c\overline{s}$ →γg system, results are in Table 2.

Table 2. Strength coupling data at T_c =113 and 130 MeV for $c\overline{s}$ →γgsystem.

$TMev$	The strength coupling α_s	
	At T_c =113 MeV	At T_c =130 MeV
170	0.39877	0.42257
190	0.38170	0.40346
210	0.36755	0.38768
230	0.35556	0.37437
250	0.34525	0.36295
270	0.33624	0.35301

Additionally, the quarks charge system can estimate using summation $\sum$ with electric charge of charm is$e_c = +2/3\,e$ and anti-strange is $e_{\overline{s}} = +1/3\,e$. The photons emission rate of the charm anti-strange interaction is determined using Eq. 16 with inserting results of photon energy from experimental data in range $E_\gamma = 1.55GeV$ [26], strength coupling from Table 2, critical temperature from Table 1 and fugacity of charm and anti-strange are λ_q= 0.06, $\lambda_{\overline{q}}$= 0.06, with annihilation coefficient is $C_{an} = 1.415$[27]. Results are listed in Tables 3 and 4 with Figures 2 and 3 respectively for both $T_c = 113 \wedge 130MeV$.

Table 3. The photon rate for$c\overline{s}$ →γg system at $T_c = 113MeV$ with λ_q=0.06, $\lambda_{\overline{q}}$=0.06 and flavor number $n_f = 7$.

	$R_\gamma\left(\frac{1}{GeV^2 fm^4}\right)$					
	T=170 Mev	T=190 Mev	T=210Mev	T=230 Mev	T=250 Mev	T=270 Mev
$E_\gamma GeV$	$\alpha_s = 0.39877$	$\alpha_s = 0.38170$	$\alpha_s = 0.36755$	$\alpha_s = 0.35556$	$\alpha_s = 0.34525$	$\alpha_s = 0.33624$
1.5	1.12322E-13	2.97258E-13	6.43228E-13	1.19194E-12	1.9483E-12	2.86169E-12
2	9.10797E-15	3.44975E-14	1.01486E-13	2.47154E-13	5.20358E-13	9.76509E-13
2.5	6.11055E-16	3.21415E-15	1.23966E-14	3.79537E-14	9.7368E-14	2.17461E-13
3	3.78798E-17	2.7432E-16	1.37384E-15	5.23133E-15	1.61569E-14	4.23625E-14
3.5	2.25082E-18	2.23586E-17	1.44824E-16	6.82934E-16	2.52752E-15	7.7411E-15
4	1.30315E-19	1.77218E-18	1.4816E-17	8.63375E-17	3.82031E-16	1.36346E-15
4.5	7.41507E-21	1.37891E-19	1.48616E-18	1.06887E-17	5.64734E-17	2.34551E-16
5	4.16763E-22	1.059E-20	1.47029E-19	1.30409E-18	8.22045E-18	3.96986E-17

Table 4. The photon rate for $c\overline{s}$ →γg system at $T_c = 130MeV$ with λ_q= 0.06, $\lambda_{\overline{q}}$= 0.06 and flavor number $n_f = 7$.

	$R_\gamma\left(\frac{1}{GeV^2 fm^4}\right)$					
	T=170 Mev	T=190 Mev	T=210 Mev	T=230 Mev	T=250 Mev	T=270 Mev
$E_\gamma GeV$	$\alpha_s = 0.42257$	$\alpha_s = 0.40346$	$\alpha_s = 0.38768$	$\alpha_s = 0.37437$	$\alpha_s = 0.36295$	$\alpha_s = 0.35301$
1.5	1.06178E-13	2.77107E-13	5.89642E-13	1.06987E-12	1.70167E-12	2.40756E-12
2	8.97316E-15	3.37944E-14	9.88312E-14	2.39175E-13	5.00139E-13	9.31538E-13
2.5	6.11703E-16	3.20526E-15	1.23162E-14	3.75669E-14	9.60131E-14	2.13605E-13
3	3.82491E-17	2.76132E-16	1.37887E-15	5.23574E-15	1.61262E-14	4.21679E-14
3.5	2.28528E-18	2.26382E-17	1.46263E-16	6.88089E-16	2.54086E-15	7.76505E-15
4	1.32819E-19	1.80161E-18	1.50272E-17	8.73823E-17	3.85885E-16	1.37463E-15
4.5	7.57914E-21	1.40599E-19	1.51205E-18	1.08535E-17	5.72396E-17	2.37329E-16
5	4.26932E-22	1.08229E-20	1.49949E-19	1.32752E-18	8.35375E-18	4.02785E-17

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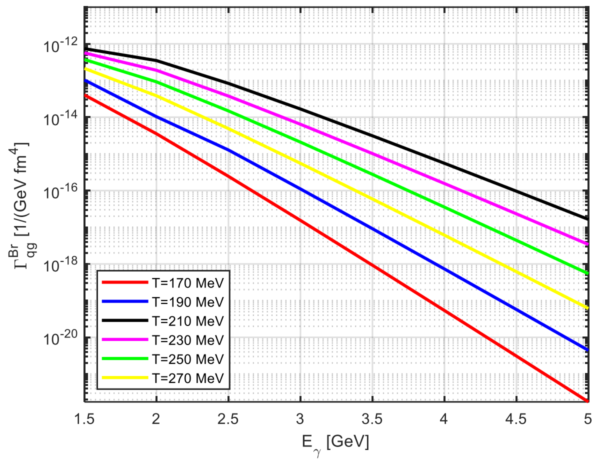

Figure 2. The photon rate$R_\gamma$for$c\overline{s}$ →γg system at $T_c = 113MeV$, λ_q=$\lambda_{\overline{q}}$=0.06 and $n_f = 7$.

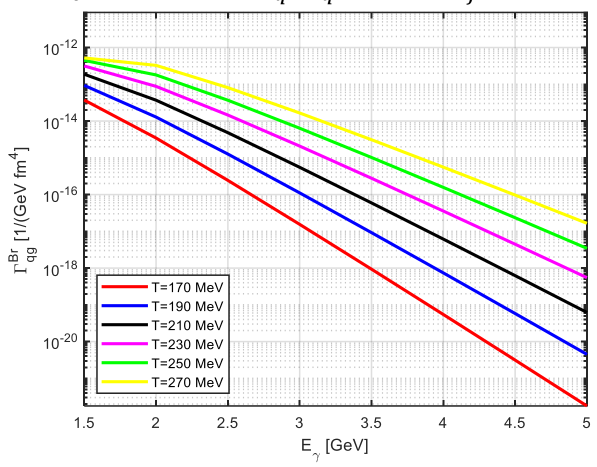

Figure 3. The photon rate$R_\gamma$for$c\overline{s}$ →γg system at $T_c = 130MeV$, λ_q=$\lambda_{\overline{q}}$= 0.06 and $n_f = 7$.

DISCUSSIONS

The photons rate in Eq. 16 is related to photons energy and strength coupling and it is influenced by the critical temperature, temperature of system and flavour number of the charm quark interaction with anti-strange quark in annihilation processes. The strength coupling in the Table 2 decreases with the increase of the temperature of system from 170 MeV to 270 MeV, because of the decreased the coupling between quarks and gluon with increased the temperature of system. On the other hand, strength coupling was function of critical temperature, it can be seen the strength coupling increases with increase the critical temperature from 113 MeV to 130 MeV. The strength coupling can be calculated by entering the different critical temperatures and temperatures of the system used with the number of flavor quarks n_f = 7 in Eq. 17. The strength coupling is almost dependent on critical temperature, its increases with increases the critical temperature and vice versa**.** In the framework of our theoretical calculation of photons rate for the range photons energy (1.5–5.0 GeV) and temperature system ($170MeV \leq T$ and $T\leq 270MeV$is done in both Tables 3 and 4 and its plotted in Figures 2 and 3 respectively.

For charm anti-strange interaction photons rate of the order of $\frac{1}{GeV^2 fm^4}$and for $\alpha_s = 0.33624$ and T = 270 MeV we obtain the maximum rate $R_\gamma = 2.86169 \times 10^{-12} \frac{1}{GeV^2 fm^4}$ at $E_\gamma = 1.5GeV$ and the photon rate reach to minimum $R_\gamma = 4.16763 \times 10^{-22} \frac{1}{GeV^2 fm^4}$at $\alpha_s = 0.39877$ and T = 170 Mev with critical temperature $T_c = 113MeV$. Similarly , the photons rate reach to maximum $R_\gamma = 2.40756 \times 10^{-12}$ at $E_\gamma = 1.5GeV$ for $\alpha_s = 0.35301$and T = 270 MeV, and the photon rate reach to minimum $R_\gamma = 4.26932 \times 10^{-22}$at $\alpha_s = 0.42257$and T=170 Mev with critical temperature $T_c = 130MeV$.

Figures 2 and 3 show that photon yield rate decrease with increase the photons enrgyat different critical temperature and variety temperatures of system with flavors number $n_f = 7$in annihilation process. It is seen that photons emission rate is found to be increased with the increased temperature of the system and decreased the strength coupling in both critical temperature of quark flavour $n_f = 7$. However, the photons ratein Table 4 and Figure 3 with the critical temperature 130 MeV is large than photon rate in Table 3 and Figure 2 with critical temperature 113 MeV. As we can see, the contribution of photons rate produce increases with increases the temperature of system T > 170 MeV and stay the photons rate instable to more increase with the increase temperature and reach max at temperature T = 270MeV. However, we can show the photon rate in both Tables 3 and 4 and two Figures 2 and 3 are large at the photons energy $E_\gamma \geq 2GeV$. In fact, we find the photons rate increase in the high and to effect by increase temperature, with decrease strength coupling in both Tables 3 and 4 for critical temperature$T_c = 113MeV$ and $T_c = 130MeV$ for $c\overline{s}$ →γg system with flavor number $n_f = 7$.

CONCLUSIONS

In this work, it was concluded that the coupling strength is directly proportional to the critical temperature and inversely proportional to the temperature of the system. We have shown that strength coupling and critical temperature are a pure effect on the photons rate of the charm and anti-strange annihilation interaction at the large range of temperature system (170-270MeV). Results of photons rate produce indicate that photons spectra is a function of photon energy distribution, strength coupling and critical temperature. Thus, such a non-trivial photon energy distribution and strength coupling dependence of temperature of system is a unique feature of photons spectrum. Moreover, the both temperature system and critical temperature parameters are playing a key role in the photons rate. In conclusion, the emission of the photon production in the high energy collisions is an excellent process to study nucleons.

Disclosure and conflict of interest: The authors declare that they have no conflicts of interest.

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