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Theoretical Study of the Effect of the Coupling Constant Strength on the Photons Rate Yield for Quark Gluon Interaction

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Abstract

Rate of photon yield in a quark-gluon interaction exhibits of the coupling constant strength and temperature dependence have been studied theoretically .The estimation of the coupling constant strength is very important tool for the investigation of the QCD, which has been applied to the dynamical quarks n_f= 3, 5, ,and gluon n_f= 0 . Depending upon the the coupling constant data ,it shows that the strong force is relatively weak for quarks, and the two quarks move farther apart the force becomes stronger. The weakness of interaction at short distance is called asymptotic freedom, while the strength of the long distance is called confinement **.**Rate of the photon yield in a quark-gluon interaction which investigation due to the electric charge of the quark with color quantum number. Photon’s rate has been calculated increasing with increases in temperature and decreasing the coupling constant and photon’s yield from the system has height fever number larger than system has low fever number .

دراسة نظرية لتاثير شدة ثابت الازدواج على معدل الحاصل الفوتوني لتفاعل كوارك–كلون

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الملخص

معدل الحاصل الفوتوني في عملية تفاعل الكوارك – كلوون درست نظريا وفقا لثابت الازدواج ودرجة الحرارة .حساب شدة ثابت الازدواج هو اداة مهمة لفهم النظرية الكمية اللونية والتي تفسر حركية الكوارك . اعتمادا على نتائج ثابت شدة الازدواج ،نرى ان القوى القوية تضعف للكواركات ولكواركين يتحركان بعيدا عن بعضهما فان القوة تصبح قوية.التفاعل الضعيف للمسافات القريبة يسمى السلوك الحر بينما الربط للمسافات البعيدة يسمى الحصر. معدل الحاصل الفوتوني في عملية تفاعل الكوارك–كلوون عولجت نسبة الى الشحنة الكهربائية للكوارك مع العدد الكمي اللوني للكلوون . معدل الحاصل الفوتوني المحسوب كان متزايدا بزيادة درجات الحرارة وتناقص ثابت الازدواج .

الكلمات المفتاحية: دراسة نظرية، شدة ثابت الاقتران، معدل الحاصل الفوتوني، تفاعل كوارك–كلون.

1- Introduction

Over the past twenty years, one of the most important aims in the heavy-ion experiments is to explore a new form of matter (the quark-gluon interaction) which has been predicted by the quantum chromodynamics at finite temperature [1]. Quantum Chromodynamics is a field theory which describes the strong interaction between the quarks and gluons. It is generally assumed that all fundamental particles (among them quarks and gluons) are represented by local quantum fields. In particle physics there is a consensus to describe all local fields by quantum field theories, and QCD is one such theory. QCD, in its attempt to describe the strong interactions, introduces the concept of quarks and colour. The quark fields represent the matter fields, and although they are not directly observable, they form hadrons which are observed in nature[2]. In 1964 quarks were introduced independently by Gell-Mann, and Zweig as building blocks of hadronic matter. As far as we know today, quarks are indivisible elementary particles. Hadrons are divided into two groups. One group called baryons, consisting of three quarks (*qqq*) like protons and neutrons. The other group called mesons, consisting of a quark-antiquark pair (*qq*) like pions and kaons[3]. In the standard model of quark gluon interaction, there are six quarkfavors u; d; s; c; t and b and three quark colors R; W; and B. The quarks are matter fields. The potential of the radiated gluon field also has SU (3) symmetry, and in the standard model the various gluons are considered to be a massless particles[4]. Table(1) show some properties of quarks [5].

Table (1): Properties of quark flavors, their relative electric charges and masses [5].

Quarks		
Quark Flavor	Electric Charge	Mass
U (up)	$+2/3e$	1.5 to $3.3\,\mathrm{MeV}/c^2$
D (down)	$-1/3e$	3.5 to $6.0\,\mathrm{MeV}/c^2$
C (charm)	$+2/3e$	$1.27^{+0.07}_{-0.11}\,\mathrm{GeV}/c^2$
S (strange)	$-1/3e$	$104^{+26}_{-34}\,\mathrm{MeV}/c^2$
T (top)	$+2/3e$	$171.2 \pm 2.1\,\mathrm{GeV}/c^2$
B (bottom)	$-1/3e$	$4.20^{+0.17}_{-0.07}\,\mathrm{GeV}/c^2$

Photons are produced mainly in charged particle scattering. The production of direct photons was predicted as a good signature for the study of a quark – gluon [6].The term "direct photon" refers to those photons which are produced in the hard-scattering subprocess and are not decay products of some particle. photons can only interact electromagnetically and so any photons produced in the quark-gluon phase are likely to survive until detected. The dominant source of photon production in a quark-gluon was originally thought to be gq → γq(with a small contribution from $q\bar{q}$ → γg), and that of a thermal. The result of which was that photon production rates in a quark-gluon and hadrons gas were thought to be similar: i.e. photon production was dependent on temperature, but not necessarily a signature of a quark-gluon[7]. The strength of the quark-gluon interaction, characterized by the strong coupling constant α_s. As a consequence, quarks can only exist in bound states, a property known as color confinement. For large momentum transfer, it is possible to calculate QCD processes accurately using a perturbative expansion in α_s. This large momentum transfer is known as a hard scale which can also be defined as the transverse energy of a jet or the mass of a heavy quark[8]. The produce of the direct photons in two type processes: i- Quantum chromodynamics Compton sub process gq → γq and ii-sub process$q\bar{q}$→ γg. In this paper ,we can study and calculate the Gama rate produced for three quarks system interaction and therefore one can be described the Quantum chromodynamics completely depending on the our results .

2- Theory

Quantum chromodynamics based on quantum field theory explained and describe the strong force between quarks and gluons particles with a color charge through the coupling constant.To investigate the photon's rate as a potential signature of quark-gluon interaction, one must convolute the rates with the space-time of the nucleus-nucleus collision. Photon's rate,$\Gamma_\gamma(\alpha_s\,,T)$ is the number of photons dN with energy $E_\gamma$emitted per unit volume per unit time in the three-momentum interval $[P_\gamma, P_\gamma+d^3]$,it is given in limit $E_\gamma \gg T$ by[9].

$$\Gamma_\gamma(\alpha_s\,,T) = \frac{n_c C_F}{8\pi^2}\left(\sum_f e_f^2\right)\alpha\alpha_s\, Ln\left(\frac{2.912E_\gamma}{4\pi\alpha_s T}\right)T^2 e^{-\frac{E_\gamma}{T}} \qquad (1)$$

Where n_c is the colour quantum number ,e_f is the electric charge of the quark, α is the QED coupling constant $\alpha = \frac{e^2}{4\pi\varepsilon_o\hbar c} \approx 1/137$,and C_F is the corresponding Casimiroperator of the fundamental representation of color SU(3). The C_F is given by [10].

$$C_F = \frac{{n_c}^2-1}{2n_c} \qquad (2)$$

The effective coupling constant of the QCD depending on the μ^2scale by renormalized equation [11].

$$\mu^2 \frac{\partial \alpha_s}{\partial \mu^2} = \beta(\alpha_s) \qquad (3)$$

Where $\beta(\alpha_s)$ is the function for coupling constant $\alpha_s = \frac{{g_s}^2}{4\pi}$ and given by [12].

$$\beta(\alpha_s) = -\alpha_s[\beta_o \frac{\alpha_s}{4\pi} + \beta_1 \left(\frac{\alpha_s}{4\pi}\right)^2 + \beta_2 \left(\frac{\alpha_s}{4\pi}\right)^3 + \beta_3 \left(\frac{\alpha_s}{4\pi}\right)^4 + \cdots \dots \dots] \qquad (4)$$

For least order solving ,we inserting only the first term of the power expansion of $\beta(\alpha_s)$ in Eq.(3) ,and integrating both side results .

$$\frac{1}{\alpha_s(\mu^2)} = \frac{1}{\alpha_s(\mu_0^2)} - \frac{\beta_o}{4\pi} ln \frac{\mu^2}{\mu_0^2} \qquad (5)$$

On the other hand the mass scale $\mu^2 = {\Lambda_{QCD}}^2$is also generated and αs becomes too large for the perturbative approach to be valid.

$$\frac{1}{\alpha_s(\mu^2 = {\Lambda_{QCD}}^2)} = 0 \rightarrow \alpha_s\left({\Lambda_{QCD}}^2\right) \qquad (6)$$

Choosing $\Lambda_{QCD} = \mu_o$, where Λ_{QCD} is a scale parameter of QCD, and Eq. (6) can rewrite as,

$$\alpha_s(\mu^2) = \frac{4\pi}{\beta_o ln \frac{\mu^2}{{\Lambda_{QCD}}^2}} \qquad (7)$$

Where[13].

$$\beta_o = \frac{11}{3} n_c - \frac{2}{3} n_f = 11 - \frac{2}{3} n_f, \beta_1 = 51 - \frac{19}{3} n_f, \beta_2 = 2857 - \frac{5033}{9} n_f + \frac{325}{27} n_f^2 \qquad (8)$$

Where n_c is the number of colors and n_f is the number of quark flavors.

Inserting Eq.(8) in Eq.(7) ,and simply to reduced to.

$$\alpha_s(\mu) = \frac{6\pi}{(33 - 2n_f) ln \frac{\mu}{\Lambda_{QCD}}} \qquad (9)$$

For thermal energy $\Lambda_{QCD} = T_c$ and $\mu \approx 8T$ for high energy collision ,Eq.(9) may be written by.

$$\alpha_s(T) = \frac{6\pi}{(33 - 2n_f) Ln(\frac{8T}{T_c})} \qquad (10)$$

where T_c is the transition temperature characterizes the critical point in which quarks and gluons become confined . substituting Eq.(10) in Eq.(1) ,we get :

$$\Gamma_\gamma(\alpha_s, T) = \frac{3({n_c}^2 - 1)}{8\pi} \left(\sum_f e_f^2\right) \frac{\alpha}{(33 - 2n_f) Ln(\frac{8T}{T_c})} Ln(\frac{2.912 E_\gamma}{4\pi\alpha_s T}) T^2 e^{-\frac{E_\gamma}{T}} \qquad (11)$$

3- Results

In the systems of quark-gluon, one of the most important parameter for the studies and calculated the photon's yield rate is the strength coupling constant α_s (T). It is not constant but varies with scale .This is analogous to the fine structure constant α , that used to represent the coupling strength in QED. It can be evaluated theoretically using the Eq.(10) by using Matlab program version 7 for the thermal energy T=150 to 350 MeV. To calculate the strength coupling constant α_s (T) involved estimated the values of flavors for quarks in the quark-gluon system using expression $n_f = \sum_{i=1}^{6} n_{fi}$. Inserting the values of flavors for quarks $n_f = 3$ for $u - d$ quarks system and $n_f = 5$ for $u - \bar{c}$ quarks ,with critical temperature $T_c = 144$MeV in Eq.(10),we can evaluated the values of coupling constant α_s (T) for $u - d$,and for $u - \bar{c}$ quarks system, results are shown in Table (1).

Table(1):Results of strength coupling constant α_s(T)GeV for $u - d$,and for $u - \bar{c}$ quark

T (MeV)	α_s(T)GeV	
	$n_f = 3$	$n_f = 5$
150	0.3292Ge	0.3865
175	0.3069	0.3603
200	0.2899	0.3403
225	0.2764	0.3244
250	0.2653	0.3114
275	0.2560	0.3005
300	0.2481	0.2912
325	0.2412	0.2832
350	0.2352	0.2761

To calculate the rate of photon's yield for both systems ,we must use the electric charge of the quark with flavor (f) by $\sum_f e_f^2$ in units of the electron charge e. Next, we can calculate the rate of photon's yield for both systems ($ud \rightarrow \gamma g$and $u\bar{c} \rightarrow \gamma g$) by inserting the values of α_s(T)GeV, $\sum_f e_f^2$, E_γ =0.5-5 GeV [12],, the colour quantum number n_c=3 in Eq.(11) with the quantum electromagnetic coupling constant α≈ 1/137, and the calculated Casimiro operator $C_F$from Eq.(2), results of the photon's yield rate has been summarized in Table (2) and figure (1)for $ud \rightarrow \gamma g$, and Table (3) and figure (2)for $u\bar{c} \rightarrow \gamma g$ systems.

Table(2):Results of the photon's yields rate for $ud \rightarrow \gamma g$ system

E_γ(GeV)	$\Gamma_\gamma(\alpha_s, T) \frac{1}{GeV^2 fm^4}$			
	T=150MeV	T=200MeV	T=250MeV	T= 300 MeV
	$\alpha_s(T) = 0.3292GeV$	$\alpha_s(T) = 0.2899GeV$	$\alpha_s(T) = 2653\ GeV$	$\alpha_s(T) = 0.2461GeV$
1	2.99×10^{-9}	2.22×10^{-8}	7.80×10^{-8}	1.85×10^{-7}
1.5	$1,34\times 10^{-10}$	2.35×10^{-9}	1.39×10^{-8}	$4,74 \times 10^{-8}$
2	5.51×10^{-12}	2.24×10^{-10}	2.22×10^{-9}	1.06×10^{-8}
2.5	2.16×10^{-13}	2.04×10^{-11}	3.35×10^{-10}	2.25×10^{-9}
3	8.29×10^{-15}	1.81×10^{-12}	4.91×10^{-11}	4.63×10^{-10}

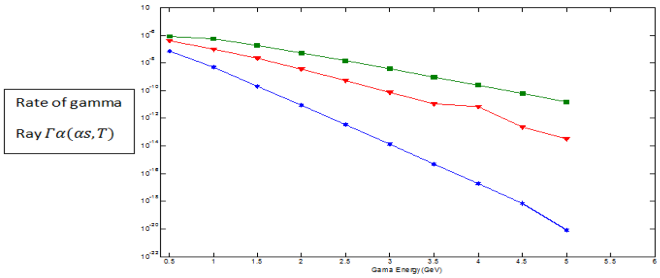

Figure (1): Rate of photon's yield for $ud \rightarrow \gamma g$ system. The Gama energy E_γ and temperatures T dependence of the rate of photon production are presented for three temperatures T = 150 MeV ,T = 250 MeV, and T=350MeV .

Table(3):Results of the photon's yield rate for $u\bar{c} \rightarrow \gamma g$ system

E_γ(GeV)	$\Gamma_\gamma(\alpha_s,T)\frac{1}{GeV^2fm^4}$			
	T=150MeV	T=200MeV	T=250MeV	T= 300 MeV
	$\alpha_s(T) = 0.3865GeV$	$\alpha_s(T) = 0.3403GeV$	$\alpha_s(T) = 0.3114\ GeV$	$\alpha_s(T) = 0.2912GeV$
1	5.04×10^{-9}	3.69×10^{-8}	1.27×10^{-7}	2.99×10^{-7}
1.5	2.32×10^{-10}	4.03×10^{-9}	2.37×10^{-8}	8.01×10^{-8}
2	9.62×10^{-12}	3.89×10^{-10}	3.82×10^{-9}	1.82×10^{-8}
2.5	3.80×10^{-13}	3.57×10^{-11}	5.82×10^{-10}	3.91×10^{-9}
3	1.46×10^{-14}	3.18×10^{-12}	8.60×10^{-11}	8.11×10^{-10}

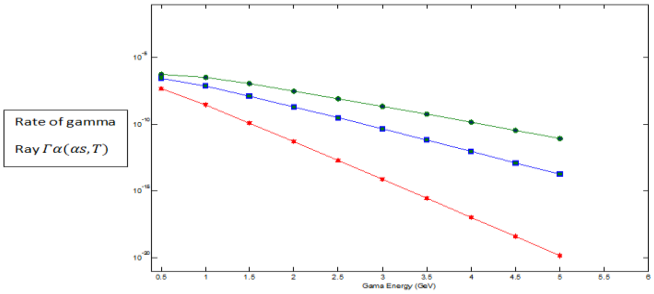

Figure (2): Rate of photon's yield for $u\bar{c} \rightarrow \gamma g$ system. The Gama energy E_γ and temperatures T dependence of the rate of photon production are presented for three temperatures T = 150 MeV ,T = 250 MeV, and T=300MeV .

4- Discussion

Depending on the QCD theory ,we exhibit many features for the high energy physics ,which will be discussed to somewhat more detail for quark-gluon interaction. One of these the coupling constant becomes scale dependent that's shown from Eq.(10) ,it is clear that for small energy scales T= 150 MeV, the coupling is strong [$\alpha_s(T) = 0.3292GeV$ for $u - d$ system , and $\alpha_s(T) = 0.3865GeV$ for$u - \bar{c}$ system] and the $\alpha_s(T)$ approaches to 0 when Tincreases to infinity . This indicate that when the two quarks are close to each other the strong force is relatively weak or the quantum chromodynamics at small length scale (high energy T= 300 V) leads to small of the coupling strength . This means that the strong force is weak if the quarks are close to each other and called asymptotic freedom. On the other hand, when two quarks move farther apart the force becomes stronger and the strength of the long distance is called confinement. Data results in Tables(2and3) and figures (1-2) show that the rates of photons are increased when decreases α_s(T) with increasing T and vice versa. This because of at the short distance between the quark and anti-quark pair, have the strength of the coupling is small. In particular the coupling strength of the strong interaction becomes weak as the T is larger in a process (or vice versa) and quarks become free at high energy and called asymptotic freedom. Also at a long distance limit that enough to create a new quark and anti-quark pair, the binding of the original quark and anti-quark pair breaks and each quark and anti-quark are bound with the new quark and anti-quark into new two quark and anti-quark pairs that is view in figure(3). Short distance between the quark and other quark or anti quark pair has small strength of the coupling, and the coupling strength of the strong interaction becomes weak as the T is larger in a process (or vice versa) and quarks become free at high energy and called asymptotic freedom.

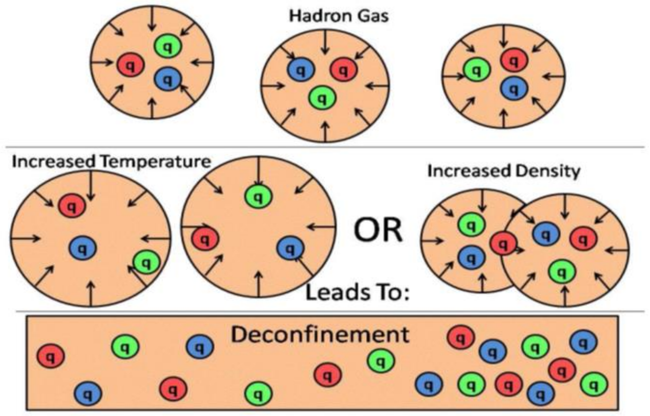

Figure 3: Deconfinement representation [5].

Rates of photons are increased for weak quark-gluon interaction due to short distance and asymptotic behavior, and the rate of photons are decreases at long distance and called confinement. On the other hand The rate of photons process in the $ud \rightarrow \gamma g, and\ u\bar{c} \rightarrow \gamma g$ systems can be traced back to the factor $T^2 e^{-\frac{E_\gamma}{T}}$ that favors the production of photons. Figure1 and figure 2 show that the rate depending on the energy of gamma $E_\gamma$for temperatures, T = 150-300 MeV respectively ,and decay is too slow.

5- Conclusions

We have seen that in strong interaction of the quark-gluon system dependent on our understanding and description of quantum cromodynamic . The force between a quarks at short distances arises due to gluon exchange to rearrange the colour structure of the final state . We conclude that the coupling constant of the QCD in the high-temperature T= 300 MeV is small and quarks are close to each other **.**It is asymptotic freedom behavior of quarks**.** The coupling varies as a function of the temperature T. We find that the strength coupling constant influence strongly on the photon's rate yield depending on the temperature .The photon's rate is inversely proportional to the temperature at asymptotic separation and the resolution energy of gamma, in the other word , the rates of photons are increased when decrease α_s(T) with increasing T and vice versa. Also we conclusion that the force become strong when two quarks move farther and called confinement, and the rate of photons are decreased.

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