Theoretical Study of the Behavior of Quarks at the Quark Gluon interaction on Compton Scattering

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دراسة نظرية لسلوك الكواركات في تفاعل كوارك – كلون في استطارة كومبتن

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المستخلص

هدف هذا البحث هو توضيح سلوك الكواركات لحالتي الحصر والسلوك الحر اعتماداً على النظرية الكمية اللونية (QCD). انبعاث الفوتونات هي اداة مهمة لتحسس تفاعل كوارك- كلون في التفاعلات النووية للطاقات العالية. حسب ثابت الازدواج الفعال حسب باستعمال التقريب الاول للمعادلات المعيرة. حسب ثابت الازدواج الفعال α_{esc} كدالة لزخم الانتقال الفعال ودرجة الحرارة . درست الخصائص الحرجة اعتماداً على النظرية الكمية اللونية لتحليل سلوك الحصر والسلوك الحر للكوارك في درجات الحرارة العالية. اختبرت الخصائص مع نتائج النظرية الكمية اللونية.

الكلمات المفتاحية: دراسة نظرية، كوارك – كلون، استطارة كومبتن.

Abstract

The aim of this work is to explain the behavior of quarks state confinement, and asymptotic freedom depending on the quantum chromodynamic theory QCD . The photons emission are very important tool to probing the quark gluon interaction at nuclear collisions for high energy. The effective coupling constant have been estimated using a first leading approximation for renormalization equation .The effective coupling constant $\alpha_{esc}(P_{eff})$ estimated as a function of effective transfer momentum and temperature. The critical properties have been studied depending on the QCD theory to analysis the asymptotic freedom and confinement behavior at high temperatures. This properties is tested with results of the QCD theory.

Key world : Theoretical Study, Quark Gluon , Compton Scattering.

Introduction

The quark-gluon interacting matter is main objective idea of ultrarelativistic collisions[1] and existence of such confined and deconfined state is due to the central collisions and it has becoming a subject matter of heavy-ion collision at the at Relativistic Heavy Ion-Collision (RHIC),the CERN Large Hadron collider(LHC)and at Large Hadron Collider (LHC) [2].Elementary particle physics deals with the quark-gluon interacting matter and the study of the ultimate constituents of matter as well as of their interactions. [3]. There are many type of photons emission signatures for its quark gluon system, each of have advantages and disadvantages and there are considering the best methods to probe the quantum chromodynamic [4]. Until the 1960, physicists were confused by the large number and variety of subatomic particles being discovered. They were trying to find a pattern that would provide a better understanding of the variety of particles[5].Gell-Mann and Zweig introduced independently the quarks particles to discussion the building blocks of hadronic matter in 1964. Today, the quarks are known an indivisible fundamental elementary particles. The quarks inside the proton and neutron are held together by the strong nuclear force, which is transmitted by uncharged particles called gluons. In addition, corresponding to each quark is an antiquark which has the same mass, but opposite charge[6]. Elementary particles can be categorized into hadrons and leptons in accord with whether they participate in the strong interaction or not. Hadrons participate in the strong interaction, while leptons do not. All hadrons are composites of quarks There are six types of quarks denoted as six different flavors: up, down, charm, strange, top, and bottom, which are usually grouped into three generations: [Up; Down], [Charm; Strange] , [Top; Bottom] . Color charge is a fundamental property of quarks, which has analogies with the notion of electric charge of particles. There are three varieties of color charges: red, green, and blue. An anti-quark's color is anti-red, anti-green, or anti-blue. Quarks and anti-quarks also hold electric charges but they are fractional, $+{}^{2}/_{3}$ for Up ,Charm and Top and $-{}^{1}/_{3}$ for Down, Strange and Bottom[7].The interaction of quarks depending on the strength that's describing by the effective of strong coupling constant for the strong interaction, $\alpha_{esc}(P_{eff})$. The effective of strength of $\alpha_{esc}(P_{eff})$ as a function of the effective transfer momentum $P_{eff}$of the quark gluon interaction [8,9] .The The effective of strength of $\alpha_{esc}(P_{eff})$, with increasing of the effective momentum transfer P_{eff} leads to the confinement and deconfinment phenomenon [10]. In this our paper we can focuses on the behavior of quarks confinement and deconfinment phenomena in the quark-gluon interaction system at Compton scattering processes according to the quantum chromodynamic theory .

Theory

We assume that quarks energy collision at equilibrium have been achieved when the effective transfer momentum become isotropic. Beyond that assume the photons have been produce at the collisions of primary hard parton. The relationship between the invariant photon production rate of photon emitted per unit time and per unit volume as given by[11].

$$\mathbb{R}_{Compton}\left(\alpha_{esc}, T, E_{phot}\right) = E\frac{dN}{d^3Pd^4x} = -\frac{1}{(2\pi)^3}\,\mathrm{Im}\prod\nolimits^{R}_{\mu\vartheta}\frac{1}{e^{E_i/T}-1}\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where E_γ is the energy of the emitted photon and $\prod^{R}_{\mu\vartheta}(E,q)$ is the retarded photon self energy for the finite temperature T . The retarded photon self-energy due to spectral representation can be given as [12].

$$\mathrm{Im}\prod_{\mu}^{R,\mu} = -\frac{10\pi}{3} e^2 \sum e_{QCD}^2 \left(e^{\frac{E_i}{T}} - 1\right) \times \int \frac{d^3k}{(2\pi)^3} \int_{-\infty}^{\infty} dw \int_{-\infty}^{\infty} dw^{\sim}\, \delta(E - w - w^{\sim})[f_{FD(q)}(w).\, f_{BE(g)}(w^{\sim})] \mathrm{Tr}[\xi^{\mu}(k, \bar{k}, -p)\rho^{*}(w, \bar{k})\rho(w - E, \bar{k} - \bar{p})\xi^{\vartheta}(-\bar{k}, -k, p)] \ldots\ldots\ldots\ldots(2)$$

Then integral term in Eq.(2) could be solving to .

$$\mathrm{Im}\prod_{\mu}^{R,\mu} = -4\pi \frac{5}{12\pi^2} e^2 \sum e_{QCD}^2 \left(e^{\frac{E_i}{T}} - 1\right) \times \left[e^{-\frac{E_{phot}}{T}}\right] \{2m_q^2 \int_k^{\mu} \frac{w_+(k) - w_-(k)}{m_q^2} dk + \Omega_{corection} \ldots\ldots\ldots\ldots(3)$$

On the other hand ,we should be evaluation integral in the Eq.(3) and result.

$$2\int_k^{\mu} \frac{w_+(k) - w_-(k)}{m_q^2} dk = 2\int_k^{\mu} \frac{1}{k} dk\, \mathrm{Ln}\frac{\mu^2}{k^2}) \ldots\ldots(4)$$

Then by substituting the Eq.(4) in Eq.(3) result to.

$$\mathrm{Im}\prod_{\mu}^{R,\mu} = -4\pi \frac{5}{12\pi^2} e^2 \sum e_{QCD}^2 \left(e^{\frac{E_i}{T}} - 1\right) \times \left[e^{-\frac{E_{phot}}{T}}\right] (m_q^2 \mathrm{Ln}\frac{\mu^2}{k^2} + \Omega_{corection} \ldots\ldots\ldots(5)$$

Where $\Omega_{corection}$ is the corection term given by [13].

$$\Omega_{corection} = \int k dk \beta_{\pm}(w, k) \times \theta(k^2 - w^2) \cong m_q^2 (\frac{1}{2}\, \theta_{Euler}) \ldots\ldots\ldots\ldots(6)$$

where θ_{Euler} is the Euler constant equally 0.577216 [14]. By inserting Eq.(5) in Eq.(6). for get

$$\mathrm{Im}\prod_{\mu}^{R,\mu} = -4\pi \frac{5}{12\pi^2} e^2 \left(e^{\frac{E_i}{T}} - 1\right) \left[e^{-\frac{E_{phot}}{T}}\right] [m_q^2 \mathrm{Ln}\frac{\mu^2}{k^2} + m_q^2 \left(\frac{1}{2} - \theta_{Euler}\right)] \ldots\ldots\ldots(7)$$

Inserting Eq.(7) in Eq.(1) give us the photons emission rate .

$$E\frac{dN}{d^3Pd^4x}\left(\alpha_{esc}, T, E_{phot}\right) = \frac{1}{8\pi^4} \times \frac{5}{3} e^2 \sum e_{QCD}^2 \times \left[e^{-\frac{E_{phot}}{T}}\right] \times m_q^2 [\mathrm{Ln}\frac{\mu^2}{k^2} + \frac{1}{2} - \theta_{Euler}] \ldots\ldots\ldots\ldots(8)$$

Where $\alpha = \frac{e^2}{4\pi}$ [15],and m_q^2 is the square of quarks masses given by [16].

$$m_q^2 \frac{g^2 C_F T^2}{4} \ldots\ldots\ldots\ldots(9)$$

Here $g^2 = 4\pi\alpha_{esc}$ is the strong quantum chromodynamic gauge that's related with effective strength coupling α_{esc} , T is the thermal energy and C_F is the Casimir of quark representation relative to colour number N_c and given by[17].

$$C_F \frac{N_c^2 - 1}{2N_c} \ldots\ldots\ldots\ldots(10)$$

The photons emission rate in Eq.(7) with $\alpha = \frac{e^2}{4\pi}$ and $g^2 = 4\pi\alpha_{esc}$ is given .

$$E\frac{dN}{d^3Pd^4x}(\alpha_{esc},T,E_{phot}) = \frac{1}{8\pi^4}\times\frac{5}{3}\sum e^2_{QCD}\times 4\pi\alpha\left[e^{-\frac{E_{phot}}{T}}\right]\times\frac{4\pi\alpha_{esc}T^2}{4}\times\frac{8}{6}[Ln\frac{\mu^2}{k^2}+\frac{1}{2}-\theta_{Euler}] \quad ...(11)$$

For lower limit of k and μ from $k\sim gT$, and $\mu\sim\sqrt{2ET}$ the Eq. (11) becomes.

$$E\frac{dN}{d^3Pd^4x}(\alpha_{esc},T,E_{phot}) = \frac{10\alpha\alpha_{esc}}{9\pi^2}\sum e^2_{QCD}\; T^2 e^{-\frac{E_{phot}}{T}}[Ln(\frac{2ET}{4\pi\alpha_{esc}T})+\frac{1}{2}-\theta_{Euler}] \quad ...(12)$$

Where α is the quantum electrodynamic constant is equal($\alpha=\frac{e^2}{4\pi\varepsilon_o\hbar c}\approx\frac{1}{137}$) , e_{QCD} is the electric charge of quark. The effective of strong coupling constant at high energy collision can be written as[18].

$$\alpha_{esc}(P_{eff})\frac{6\pi}{(33-2N_F)\ln(\frac{P_{eff}}{T_c})} \quad ...(13)$$

where P_{eff} is the effective momentum transfers, T_c is the transition temperature, and N_F is the favor number.

Results

In order to understand the behavior of quarks in the quark gluon system at the Compton scattering processes, we focus on the estimation the effective strength coupling $\alpha_{esc}(P_{eff})$.The behaviors of quarks is adapted to the investigation the two state confinement and deconfinment of quarks system according to quantum scenario .Firstly we can estimation the flavor number ,color charge and electric charge of quarks to evaluation the effective strength coupling α_{esc}. Flavor number of quarks could be using $N_F = 7$ for $cg\rightarrow s\gamma$ and $tg\rightarrow u\gamma$ systems depending on formula $\sum_F N_F$ and inserting the values of flavors quantum numbers for quarks $N_f = 1,3,4$ and 6 for Up, Charm ,Strange and Top quarks . So far, the color charge could be estimation according to quantum chromodynamic theory . The quarks system have color charge in the limit of the color index, $1\leq N_C \leq 3$. The square electric charge of the quarks systems at Compton scattering e^2_{QCD} can be estimation using the summation $\sum e^2_{QCD} = \frac{5}{9}$ and $\frac{8}{9}$ for both $cg\rightarrow s\gamma$ and $tg\rightarrow u\gamma$ quakes systems . The effective strength coupling $\alpha_{esc}(P_{eff})$ at high energy can only be determined theoretically depending on the set of transfer momentum values$P_{eff} = 1.2$,1.6 ,2 and $2.4\ GeV$ by using the first least order expression in Eq.(13) and inserted the values of flavors 7 for $cg\rightarrow s\gamma$ and $tg\rightarrow u\gamma$ systems and using various values of thermal energy T = 150 ,200,250 and 300 MeV with critical temperature $T_c = 190\ MeV$, the results of α_{esc} have been shown in table (1) . The net photons rate that production from quark gluon interaction depending on the quantum consideration and the quantum chromodynamics theory at various photons energy $E_{Phot} = 1 \rightarrow 5\ GeV$ [9],and considered the interaction for one loop contributions for $cg \rightarrow s\gamma$ and $tg \rightarrow u\gamma$ systems . The photons rate have been evaluation at Compton scattering processes using Eq.(12) by inserting the values the effective strength coupling α_{esc} from table(1),the effective momentum transfer P_{eff}, quantum flavor numbers N_F= 7, for both system ,critical temperature T_c= 190 M eV and thermal energy T = 150 MeV, T = 200 MeV ,T=250 MeV andT=300MeV. The data results are summarized in tables(2) ,and (3) and figures (1) and (2) for $cg \rightarrow s\gamma$ and $tg \rightarrow u\gamma$ systems at critical temperature T_c= 190 MeV .

Table (1):Theoretical estimation of the effective strength coupling α_{esc} due to critical temperature T_c=190Mevfor $cg \rightarrow s\gamma$،and $tg \rightarrow u\gamma$ systems .

system	N_F	α_{esc} (P_{eff})			
		P_{eff}=1.2 GeV	P_{eff}=2 GeV	P_{eff}=3 GeV	P_{eff}=4 GeV
		T= 150 MeV	T= 200 MeV	T=250 MeV	T= 300 MeV
$cg \rightarrow s\gamma$	7	3211	0.4214	0.4656	0.5382
$tg \rightarrow u\gamma$	7	0.3539	0.3813	0.4212	0.4870

Table (2):The result of photon rate production $E\frac{dN}{d^3Pd^4x}(\alpha_{esc}, T, E_{phot})$in cg→sɣ sytem at Compton scattering due to T_C=190 MeV with flavor number N_F =7

E_{phot}GeV	$E\frac{dN}{d^3Pd^4x}(\alpha_{esc}, T, E_{phot})$ $\frac{1}{GeV^2fm^4}$			
	T=150MeV	T=200 MeV	T=250 MeV	T=300 MeV
	$\alpha_{esc} = 0.5382$	$\alpha_{esc} = 0.4656$	$\alpha_{esc} = 0.4214$	$\alpha_{esc} = 0.3211$
1	4.231×10^{-9}	2.628×10^{-8}	7.383×10^{-8}	1.304×10^{-7}
1.5	2.527×10^{-10}	4.064×10^{-9}	2.207×10^{-8}	6.854×10^{-8}
2	1.159×10^{-11}	4.446×10^{-10}	4.148×10^{-9}	1.883×10^{-8}
2.5	4.848×10^{-13}	4.356×10^{-11}	6.832×10^{-10}	4.418×10^{-9}
3	1.937×10^{-14}	4.050×10^{-12}	1.059×10^{-10}	9.676×10^{-10}
3.5	7.538×10^{-16}	3.654×10^{-13}	1.587×10^{-11}	2.040×10^{-10}
4	2.882×10^{-17}	3.233×10^{-14}	2.329×10^{-12}	4.200×10^{-11}
4.5	1.089×10^{-18}	$2 .823\times10^{-15}$	3.368×10^{-13}	8.513×10^{-12}
5	4.080×10^{-20}	2.442×10^{-16}	4.820×10^{-14}	1.705×10^{-12}

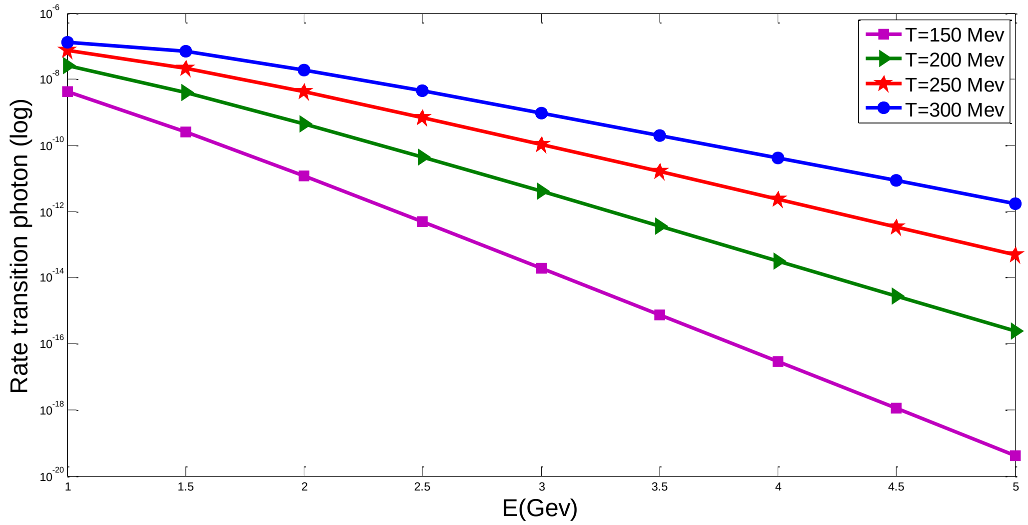

Fig. (1): Photons rate $E\frac{dN}{d^3Pd^4x}(\alpha_{esc}, T, E_{phot})$ as a function of E_{phot} for $cg \rightarrow s\gamma$ system with N_F=7, $\sum e^2 = \frac{5}{9}$, T_c= 190 MeV.

Table (3):The result of photon rate production $E\frac{dN}{d^3Pd^4x}(\alpha_{esc}, T, E_{phot})$ in tg→uɣ system at Compton scattering due to T_C=190 MeV with flavor number N_F =7.

E_{phot} GeV	$E\frac{dN}{d^3Pd^4x}(\alpha_{esc}, T, E_{phot})\ \frac{1}{GeV^2 fm^4}$			
	T=150 MeV	T=200 MeV	T=250 MeV	T=300 MeV
	$\alpha_{esc} = 0.4870$	$\alpha_{esc} = 0.4212$	$\alpha_{esc} = 0.3813$	$\alpha_{esc} = 0.3539$
1	7.145×10^{-9}	4.634×10^{-8}	1.387×10^{-7}	7.336×10^{-7}
1.5	4.022×10^{-10}	6.564×10^{-9}	3.628×10^{-8}	1.149×10^{-7}
2	1.807×10^{-11}	6.996×10^{-10}	6.590×10^{-9}	3.022×10^{-8}
2.5	7.481×10^{-13}	6.766×10^{-11}	1.068×10^{-9}	6.956×10^{-9}
3	2.969×10^{-14}	6.240×10^{-12}	1.640×10^{-10}	1.506×10^{-9}
3.5	1.150×10^{-15}	5.598×10^{-13}	2.443×10^{-11}	9.152×10^{-10}
4	4.383×10^{-17}	4.943×10^{-14}	3.568×10^{-12}	6.458×10^{-11}
4.5	1.651×10^{-18}	4.295×10^{-15}	5.141×10^{-13}	1.303×10^{-11}
5	6.174×10^{-20}	3.706×10^{-16}	7.336×10^{-14}	2.603×10^{-12}

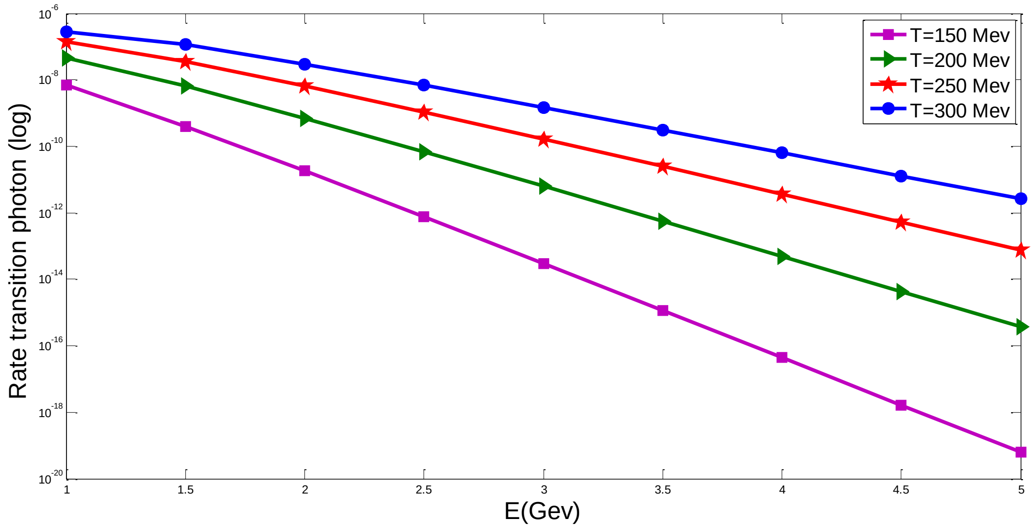

Fig. (2): Photons rate $E\frac{dN}{d^3Pd^4x}(\alpha_{esc}, T, E_{phot})$ as a function of E_{phot} for tg → uγ system with N_F =7, $\sum e^2 = \frac{8}{9}$, T_c= 190 MeV.

Discussion

The effect of confinement and deconfinment on photons rate at Compton scattering processes is done for two different cg → sγ and tg → uγ systems quark with different flavors quantum number N_F=7 for both system depending on quantum chromodynamics theory . The confinement of quarks is one of essentially to discussion the reasons of the nuclear forces have was having short range properties ,on the other hands ,the exchange of gluons were be long range. Depending on the quark–gluon Compton processes, the initial scattering state and the final scattering state could overlapping between them at high thermal energies and emotion a lot of photons until to equilibrium at hadrons phase . Following the effective strength coupling is necessary to estimation by using Eq.(13) that to be distinguish and discussion the state of quarks between the form confinement and asymptotic freedom behavior when photons emission at for quarks state interaction scattering events. For quark-gluon Compton scattering system, the quarks are the only matter particles with nonzero color while the gluon is the mediator of the strong force. It carries color and it is self-interacting, a property which proved to be essential for the asymptotic freedom of QCD. In table (1) we can show the effective strength coupling α_{eff} decreases with increasing thermal energy T until it vanishes at the critical temperature $T_c \ll 200MeV$. The value of the critical temperature is estimated around $T_c \approx 190MeV$. The total photon transition rate is given by an integral over all energy and transfer momentum of the Compton scattering interaction and may evaluation using Eq.(12) for two systems $cg \rightarrow s\gamma$ and $tg \rightarrow u\gamma$ as a relative to the effective strength coupling α_{eff} . The results of $\alpha_{eff}(P_{eff})$ increases with decreases of the effective momentum transfer P_{eff} and decreases with increases the thermal energy T , this refers to bind the quarks strongly to each other at system have small effective momentum transfer or have low thermal energy. On the other hand the effective strength coupling coupling $\alpha_s(P)$ for Compton scattering processes increasing with increasing flavor number n_f and vice versa. For Compton scattering process, the effective momentum transfer inversely proportional with the photons rate and the rate is decreasing with increasing effective momentum transfer. Factoring out the same coefficient of critical temperature and energy of interaction which appears in the leading logarithmic result Eq.(12), that indicate the contribution of inelastic quark gluon scattering processes to the leading-order emission rate in Eq.(12). From the results ,we can show from tables (1) the effective strength coupling constant $\alpha_{eff}(P_{eff})$ be small when $P_{eff} \gg T_c$ and dependence on the momentum transfer scale P_{eff} is expressed by Eq.(13). In figures (1) and (2) the photons rate for $cg \rightarrow s\gamma$ and $tg \rightarrow u\gamma$ systems as function of photons energy spectra of photons rate produced in quark gluon interaction were plotted in four curves . The curves were performed for the critical temperature , T_c= 190 MeV for the phase transition at the quark-gluon interaction .Therefore, the rate photons of quark-gluon Compton scattering interactions in tables (2 to 3) due to large momentum transfer P_{eff} should be express in the perturbative method, and the effective strength coupling constant is simply a function of the momentum scale. This refers that quarks could be close to each other and the strong force is relatively weak that's mean the quarks in deconfinement or (asymptotic freedom). On the other hand, the quarks move farther apart the force becomes stronger then the quarks in state called (confinement). However ,the behavior of quarks depending on the results of the effective strength coupling constant depending on the QCD due to the distance of the interaction is unique. This indicate that quarks behavior due to height energy at QCD is opposite the behavior at the electromagnetism effect and that's means the quarks at large distance are very attractive strength and quarks binds force to each other . The results in table (1) show that $\alpha_{eff}(P_{eff})$ increases with decreases of the effective momentum transfer P_{eff} and decreases with increases the thermal energy T , this refers to bind the quarks strongly to each other at system have small effective momentum transfer or have low thermal energy. Sufficiently at high thermal energy ,one have expected hadrons to melt , deconfinment the quarks and gluons. The behavior at small effective momentum transfer P_{eff} or large distances is more complicated, since single quarks are confinement in hadrons and cannot be observed. The conditions of quarks at low distances with high effective momentum transfer P_{eff}, as they are necessary for the asymptotic freedom, can be realized in a system that is sufficiently compressed or heated up. From the tables (2)and (3),we can show if decreasing the effective momentum transfer scale P_{eff}, the effective strength coupling constant $\alpha_{eff}(P_{eff})$ grows very large for quark-gluon interaction and rate decreases. This indicates that the quarks became freely when thermal energy be height. By same words the force at quark-gluon interaction is very weak when the quarks are close to each other and behave asymptotically freedom and the strong force become strong when two quarks move farther to each other that's confinement. It is believed a consequence of this property is that quarks become weakly interacting in Compton scattering processes occurring at very high energies or equivalently at very small distances. Therefore, we expect that at very high temperatures and/or very high densities, this many-body system will behave of deconfined quarks. The quarks that freely in the QGP bear non-vanishing color charges. However, all observed hadrons have zero color charge. Hence, at lower temperatures and densities, the dynamics of QCD becomes strongly coupled and quarks get bound into color singlet states. This phenomenon is known as confinement .We see that there must be a phase transition taking place between the hadronic and QGP phases .On the other hand the ,the effective strength coupling coupling $\alpha_s(P)$ for Compton scattering processes increasing with increasing flavor number n_f and vice versa. From tables(1) and table(2 to 3), we can show that the effective strength coupling constant for system have low flavor quantum number n_f is smaller than the effective strength coupling constant for system have height flavor quantum number n_f and the energy temperatures 300 MeV the effective coupling constant of QCD becomes weak and quark-gluon systems are collective required to separate the system have large strength is greater than it for small effective strength coupling constant . Also we can see the effective strength coupling increases with decreasing the thermal temperature . From results , We have found that photons rate increase in tables (2) to (3) are highly effected by increasing thermal energies of the $cg \rightarrow s\gamma$ and $tg \rightarrow u\gamma$ systems, and decreasing with decreases the thermal energy ,it seems the photons rate to be large near 300 MeV is considered to be exist at very hot temperature compare to that in 150 Mev. At very high excitations particles and should to be good approximation become hadronic system

Conclusion

In conclusion, we have estimated the effective strength coupling $\alpha_{esc}(P_{eff})$ carried out to understand the behavour of quarks at Compton scattering role . The effect of confinement and deconfinment on photons depending on the results of the effective strength coupling constant indicate the nuclear forces were having short range properties and should be expressed in the perturbative method . This refers that quarks could be close to each other and the strong force was weakly and the quarks in deconfinement or (asymptotic freedom). By same, the quarks move farther apart the force becomes stronger then the quarks in state called (confinement). For high thermal energy ,one have expected hadrons to melt , deconfinment the quarks and gluons.

The behavior at small effective momentum transfer P_{eff} or large distances is more complicated, since single quarks are confinement in hadrons and cannot be observed. The quarks at low distances with high effective momentum transfer P_{eff} , as they are necessary for the asymptotic freedom, can be realized in a system that is sufficiently compressed or heated up. the effective strength coupling constant $\alpha_{eff}(P_{eff})$ grows very large for quark-gluon interaction and rate decreases. This indicates that the quarks became freely when thermal energy be height.

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