Decay Constants of Heavy Vector Mesons at Finite Temperature

Elşen Veli Veliev, Kazem Azizi *, Hayriye Sundu, Gülşah Kaya, Arzu Türkan

Physics Department, Kocaeli University, Umuttepe Yerleşkesi, 41380 Izmit, Turkey
* *Physics Division, Faculty of Arts and Sciences, Doğuş University, Acıbadem-Kadıköy*

2nd International Conference on Particle Physics in Memoriam Engin Arık and Her Colleagues, Doğuş University
20-25 June 2011, Istanbul,TURKEY

Decay Constants of Heavy Vector Mesons at Finite Temperature

Decay Constants of Heavy Vector Mesons at Finite Temperature

Decay Constants of Heavy Vector Mesons at Finite Temperature

Decay Constants of Heavy Vector Mesons at Finite Temperature

Decay Constants of Heavy Vector Mesons at Finite Temperature

Introduction

Investigations of the heavy mesons play the essential role in understanding the vacuum properties of the nonperturbative QCD [1]. In particular, analysis of the variation of the parameters of the heavy quarkonia, namely bottomonium ($\bar{b}b$) and charmonium ($\bar{c}c$) in hadronic medium with respect to the temperature can give information about the QCD vacuum and transition to the quark gluon plasma (QGP) phase. Determination of the hadronic properties of the vector mesons in hot and dense QCD medium has become one of the most important research subject in the last twenty years both theoretically and experimentally. J/ψ suppression effect due to color screening can be considered as an important evidence for QGP [2]. This suppression effect has been observed experimentally at CERN and at BNL.

Introduction

Properties of the heavy mesons in vacuum have been investigated widely in the literature using the nonperturbative approaches like QCD sum rules, nonrelativistic potential models, lattice theory, heavy quark effective theory and chiral perturbation theory. QCD sum rules which is based on the operator product expansion (OPE), QCD Lagrangian and quark-hadron duality, is one of the most informative, applicable and predictive models in hadron physics [3, 4]. The thermal version of this model proposed by Bochkarev and Shaposhnikov [5]. However, in expansion of this method to finite temperature we are face to face with some difficulties. One of the complication is the interaction of the current with the particles in the medium which requires the modification of the dispersion representation [6-8]. The other complication of the thermal QCD is breakdown of the Lorentz invariance via the choice of reference frame. Thermal QCD sum rules has been successfully used for studying the thermal properties of light [9-11], heavy-light[12-14] and heavy-heavy [15-18] mesons.

Thermal QCD Sum Rules for Vector Mesons

In the present work, we calculate the decay constants f_V of the heavy vector quarkonia $J/\psi(\bar{c}c)$ and $\Upsilon(\bar{b}b)$, which are defined by the matrix element of the vector current J_μ between the vacuum and the vector-meson state,

$$\langle 0|J_\mu|V(q,\lambda)\rangle = f_V m_V \varepsilon_\mu^{(\lambda)}. \tag{1}$$

To obtain the thermal QCD sum rules for physical quantities, we need to calculate the convenient thermal correlation function in two different ways: in terms of QCD degrees of freedom and in terms of hadronic parameters. In QCD side, the correlation function is calculated via OPE which allows us expand the time ordering product of currents in terms of operators with different dimensions. We begin by considering the following two point thermal correlation function:

$$\Pi_{\mu\nu}\Big(q,T\Big) = i\int d^4x\, e^{iq\cdot x}\, Tr\Big(\rho\,\mathcal{T}\Big(J_\mu(x)J_\nu^\dagger(0)\Big)\Big), \tag{2}$$

where $J_\mu(x) =: \overline{Q}(x)\gamma_\mu Q(x)$: is the vector current and $Q = b$ or c quark field, $\mathcal{T}$ indicates the time ordered product and $\rho = e^{-\beta H}/Tre^{-\beta H}$ is the thermal density matrix of QCD at temperature $T = 1/\beta$. As we previously mentioned, the Lorentz invariance breaks down via the choice of reference frame at which the matter is at rest. However, using the four velocity vector u_μ of the matter, we can define Lorentz invariant quantities such as $\omega = u\cdot q$ and $\overline{q}^2 = \omega^2 - q^2$.

Thermal QCD Sum Rules for Vector Mesons

Using these quantities, the thermal correlation function can be expressed in terms of two independent tensors $P_{\mu\nu}$ and $Q_{\mu\nu}$ at finite temperature [9], i.e.,

$$\Pi_{\mu\nu}\left(q,T\right) = Q_{\mu\nu}\Pi_l(q^2,\omega) + P_{\mu\nu}\Pi_t(q^2,\omega), \tag{3}$$

where

$$\begin{aligned} P_{\mu\nu} &= -g_{\mu\nu} + \frac{q_\mu q_\nu}{q^2} - \frac{q^2}{\bar{q}^2}\widetilde{u}_\mu\widetilde{u}_\nu, \\ Q_{\mu\nu} &= \frac{q^4}{\bar{q}^2}\widetilde{u}_\mu\widetilde{u}_\nu, \end{aligned} \tag{4}$$

and $\widetilde{u}_\mu = u_\mu - \omega\, q_\mu/q^2$. Here the functions Π_l and Π_t are the following Lorentz invariant functions:

$$\Pi_l\left(q^2,\omega\right) = \frac{1}{\bar{q}^2}u^\mu\Pi_{\mu\nu}u^\nu, \tag{5}$$

$$\Pi_t\left(q^2,\omega\right) = -\frac{1}{2}\left(g^{\mu\nu}\Pi_{\mu\nu} + \frac{q^2}{\bar{q}^2}u^\mu\Pi_{\mu\nu}u^\nu\right). \tag{6}$$

Thermal QCD Sum Rules for Vector Mesons

It can be shown that in the limit $|\mathbf{q}| \rightarrow 0$, the function Π_t can be expressed as $\Pi_t = -\frac{1}{3} g^{\mu\nu} \Pi_{\mu\nu}$ and in this limit the functions Π_l and Π_t are related to each other $\Pi_t \Big(q_0, |\mathbf{q}| = 0 \Big) = q_0^2 \, \Pi_l \Big(q_0, |\mathbf{q}| = 0 \Big)$.
Also, the spectral representation of the thermal correlation function can be written as [9]:

$$\Pi_{l,t}\left(q_0^2, T\right) = \int_0^\infty dq_0'^2 \, \frac{\rho_{l,t}\left(q_0'^2, T\right)}{q_0'^2 + Q_0^2}, \tag{7}$$

where $Q_0^2 = -q_0^2$, and

$$\rho_{l,t}\left(q_0^2, T\right) = \frac{1}{\pi} Im \Pi_{l,t}\left(q_0^2, T\right) \tanh \frac{\beta q_0}{2}. \tag{8}$$

In our calculations, firstly we consider $\Pi_1(q, T) = g^{\mu\nu} \Pi_{\mu\nu}(q, T)$ function and we use thermal quark propagator [24]:

$$S(k) = (\gamma^\mu k_\mu + m) \left(\frac{1}{k^2 - m^2 + i\varepsilon} + 2\pi i n(|k_0|) \delta(k^2 - m^2) \right), \tag{9}$$

where $n(x) = [\exp(\beta x) + 1]^{-1}$ is the Fermi distribution function .

Thermal QCD Sum Rules for Vector Mesons

Carrying out the integral over k_0, we obtain the imaginary part of the $\Pi_1(q,T)$ in the following form:

$$Im\Pi_1(q,T) = L(q_0) + L(-q_0), \tag{10}$$

where

$$\begin{aligned} L(q_0) &= N_c \int \frac{d\mathbf{k}}{4\pi^2} \frac{\omega_1^2 - \mathbf{k}^2 + \mathbf{k}\cdot\mathbf{q} - \omega_1 q_0 - 2m^2}{\omega_1\omega_2} \\ &\times \Big([(1-n_1)(1-n_2) + n_1 n_2]\delta(q_0 - \omega_1 - \omega_2) - [(1-n_1)n_2 + (1-n_2)n_1] \\ &\times \delta(q_0 - \omega_1 + \omega_2)\Big), \end{aligned} \tag{11}$$

and $n_1 = n(\omega_1)$, $n_2 = n(\omega_2)$, $\omega_1 = \sqrt{\mathbf{k}^2 + m^2}$ and $\omega_2 = \sqrt{(\mathbf{k}-\mathbf{q})^2 + m^2}$. The term without the Fermi distribution functions shows the vacuum contribution but those including the Fermi distribution functions express medium contributions. The delta-functions in the different terms of Eq. (11) control the position of branch cuts [5].

Thermal QCD Sum Rules for Vector Mesons

After straightforward calculations, the annihilation and scattering parts of $\rho_1\left(q_0^2,T\right)=\frac{1}{\pi}Im\Pi_1\left(q_0^2,T\right)\tanh\frac{\beta q_0}{2}$ at nonzero momentum can be written as:

$$\rho_{1,a}=\frac{-3q^2}{8\pi^2}(3-v^2)\left[v-\int_{-v}^{v}dx\,n_+(x)\right]\qquad \text{for}\qquad 4m^2+\mathbf{q}^2\leq q_0^2\leq\infty, \tag{12}$$

$$\rho_{1,s}=\frac{3q^2}{16\pi^2}(3-v^2)\int_{v}^{\infty}dx\left[n_-(x)-n_+(x)\right]\qquad \text{for}\qquad q_0^2\leq\ \mathbf{q}^2, \tag{13}$$

where $v(q_0^2)=\sqrt{1-4m^2/q_0^2}$, $n_+(x)=n\left[\frac{1}{2}(q_0+|\mathbf{q}|x)\right]$ and $n_-(x)=n\left[\frac{1}{2}(|\mathbf{q}|x-q_0)\right]$.

Thermal QCD Sum Rules for Vector Mesons

From the similar manner, we can calculate also the function $\Pi_2(q,T) = u^\mu \Pi_{\mu\nu}(q,T) u^\nu$. Finally we obtained the annihilation and scattering parts of ρ_t in the following forms:

$$\rho_{t,a} = \frac{3q^2}{32\pi^2}\int_{-v}^{v} dx(2 - v^2 + x^2)[1 - 2n_+(x)], \quad (14)$$

$$\rho_{t,s} = -\frac{3q^2}{32\pi^2}\int_{v}^{\infty} dx(2 - v^2 + x^2)[n_-(x) - n_+(x)]. \quad (15)$$

Thermal QCD Sum Rules for Vector Mesons

In our calculations, we also take into account the perturbative two-loop order α_s correction to the spectral density. This correction at zero temperature can be written as [1,3]:

$$\rho_{\alpha_s}(s) = \alpha_s \frac{s}{6\pi^2} v(s)\left(3 - v^2(s)\right)\left[\frac{\pi}{2v(s)} - \frac{1}{4}\left(3 + v(s)\right)\left(\frac{\pi}{2} - \frac{3}{4\pi}\right)\right], \quad (16)$$

where, we replace the strong coupling α_s in Eq. (16) with its temperature dependent lattice improved expression $\alpha(T) = 2.095(82)\frac{g^2(T)}{4\pi}$ [16,22] where

$$g^{-2}(T) = \frac{11}{8\pi^2} \ln\left(\frac{2\pi T}{\Lambda_{\overline{MS}}}\right) + \frac{51}{88\pi^2} \ln\left[2\ln\left(\frac{2\pi T}{\Lambda_{\overline{MS}}}\right)\right]. \quad (17)$$

where $\Lambda_{\overline{MS}} = T_c/1.14(4)$ and $T_c = 0.160 GeV$.

Thermal QCD Sum Rules for Vector Mesons

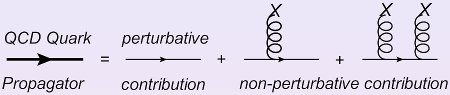

Figure: 1. Quark propagator.

In order to calculate the nonperturbative part in QCD side, we use the quark propagator in an external gluon field, $A^a_\mu(x)$ in the Fock-Schwinger gauge, $x^\mu A^a_\mu(x) = 0$. Taking into account one and two gluon lines attached to the quark line, the massive quark propagator can be written in momentum space in the following form [3]:

$$\begin{aligned} S^{aa'nonpert}(k) &= -\frac{i}{4} g (t^c)^{aa'} G^c_{\kappa\lambda}(0) \frac{1}{(k^2-m^2)^2} \left[\sigma_{\kappa\lambda}(\not{k}+m) + (\not{k}+m)\sigma_{\kappa\lambda}\right] \\ &- \frac{i}{4} g^2 (t^c t^d)^{aa'} G^c_{\alpha\beta}(0) G^d_{\mu\nu}(0) \frac{\not{k}+m}{(k^2-m^2)^5} \\ &\times (f_{\alpha\beta\mu\nu} + f_{\alpha\mu\beta\nu} + f_{\alpha\mu\nu\beta})(\not{k}+m), \end{aligned} \quad (18)$$

Thermal QCD Sum Rules for Vector Mesons

where,

$$f_{\alpha\beta\mu\nu} = \gamma_\alpha(\not{k} + m)\gamma_\beta(\not{k} + m)\gamma_\mu(\not{k} + m)\gamma_\nu. \tag{19}$$

We also need to know the expectation value $\langle TrG_{\alpha\beta}G_{\mu\nu}\rangle$. The Lorentz covariance at finite temperature allows us to write the general structure of this expectation value in the following manner:

$$\begin{aligned} \langle Tr^c G_{\alpha\beta}G_{\mu\nu}\rangle &= \frac{1}{24}(g_{\alpha\mu}g_{\beta\nu} - g_{\alpha\nu}g_{\beta\mu})\langle G^a_{\lambda\sigma}G^{a\lambda\sigma}\rangle \\ &+ \frac{1}{6}\Big[g_{\alpha\mu}g_{\beta\nu} - g_{\alpha\nu}g_{\beta\mu} - 2(u_\alpha u_\mu g_{\beta\nu} - u_\alpha u_\nu g_{\beta\mu} \\ &- u_\beta u_\mu g_{\alpha\nu} + u_\beta u_\nu g_{\alpha\mu})\Big]\langle u^\lambda \Theta^g_{\lambda\sigma}u^\sigma\rangle, \end{aligned} \tag{20}$$

where $\Theta^g_{\lambda\sigma}$ is the gluonic part of the energy - momentum tensor of the QCD.

Thermal QCD Sum Rules for Vector Mesons

Finally, up to terms required for our calculations, the non perturbative part of massive quark propagator at finite temperature can be written as:

$$
\begin{aligned}
S^{aa' nonpert}(k) &= -\frac{i}{4} g (t^c)^{aa'} G^c_{\kappa\lambda} \frac{1}{(k^2-m^2)^2}\Big[\sigma_{\kappa\lambda}(\not{k}+m)+(\not{k}+m)\sigma_{\kappa\lambda}\Big] \\
&+ \frac{i\, g^2\, \delta^{aa'}}{9\,(k^2-m^2)^4}\Big\{\frac{3m(k^2+m\,\not{k})}{4}\langle G^c_{\alpha\beta}G^{c\alpha\beta}\rangle + \Big[m\Big(k^2-4(k\cdot u)^2\Big) \\
&+ \Big(m^2-4(k\cdot u)^2\Big)\,\not{k} + 4(k\cdot u)(k^2-m^2)\,\not{u}\Big]\langle u^\alpha \Theta^g_{\alpha\beta} u^\beta\rangle\Big\}. \qquad (21)
\end{aligned}
$$

Thermal QCD Sum Rules for Vector Mesons

Using the above expression and after straightforward but lengthy calculations, the nonperturbative part in QCD side is obtained as:

$$\begin{aligned}
\Pi_t^{nonpert} &= \int_0^1 dx \Bigg\{ -\frac{\langle \alpha_s G^2 \rangle}{72\pi \Big[m^2 + q^2(-1+x)x\Big]^4} \Big[6q^6(-1+x)^4x^4 + 6m^2q^4x^2 \\
&\times (-1+x)^2(1-6x+6x^2)m^6(5-32x+42x^2-20x^3+10x^4) \\
&+ m^4q^2x\Big(-14+95x-140x^2+65^3+6x^4-2x^5\Big)\Big] \\
&- \frac{\alpha_s \langle u^\alpha \Theta^g_{\alpha\beta} u^\beta \rangle}{54\pi \Big[m^2 + q^2(-1+x)x\Big]^4} \Big[x(-1+x)\Big(4q^4x^2(1-3x+2x^2)^2 \\
&+ m^4(12-35x+21x^2+28x^3-14x^4) \\
&+ m^2q^2x(-13+55x-82x^2 \\
&+ 36x^3+6x^4-2x^5)\Big)\Big(q^2-4(q\cdot u)^2\Big)\Big]\Bigg\}, \qquad (22)
\end{aligned}$$

where, $\langle G^2 \rangle = \langle G^c_{\alpha\beta} G^{c\alpha\beta} \rangle$.

Thermal QCD Sum Rules for Vector Mesons

Now, we turn our attention to calculate the physical or phenomenological side of the correlation function. For this aim, we insert a complete set of physical intermediate state to Eq. (2) and perform integral over x. Isolating the ground state, we get

$$\Pi_{\mu\nu}(q) = \sum_{\lambda} \frac{\langle 0|J_\mu|V(q,\lambda)\rangle\langle V(q,\lambda)|J^\dagger_\nu|0\rangle}{m_V^2 - q^2} + ..., \tag{23}$$

where the hadronic states $\{|V(q,\lambda)\rangle\}$ form a complete set and ..... indicate the contributions of excited vector mesons and continuum states.

In order to obtain thermal sum rules, now we equate the spectral representation and results of operator product expansion for functions $\Pi_l(q^2,\omega)$ or $\Pi_t(q^2,\omega)$ at sufficiently high Q_0^2. When performing numerical results, we shall set $|\mathbf{q}| \to 0$ representing the rest frame of the particle. In this limit since the functions Π_l and Π_t are related to each other, it is enough to use one of them to obtain thermal sum rules. Here, we use the function Π_t.

Thermal QCD Sum Rules for Vector Mesons

Equating the OPE and hadronic representations of the correlation function and applying quark-hadron duality, our sum-rule takes the form:

$$\frac{f_V^2 Q_0^4}{(m_V^2+Q_0^2)\, m_V^2} = Q_0^4 \int_{4m^2}^{s_0} \frac{[\rho_{t,a}(s)+\rho_{\alpha_s}(s)]}{s^2(s+Q_0^2)} ds + \int_0^{|\mathbf{q}|^2} \frac{\rho_{t,s}}{s+Q_0^2} ds + \Pi_t^{nonpert}, \quad (24)$$

where, for simplicity, the total decay width of meson has been neglected. In derivation of Eq.(24) we have also used summation over polarization states, $\sum_\lambda \varepsilon_\mu^{(\lambda)^*} \varepsilon_\nu^{(\lambda)} = -(g^{\mu\nu} - q_\mu q_\nu / m_V^2)$.

Thermal QCD Sum Rules for Vector Mesons

Applying Borel transformation with respect to Q_0^2 to Eq.(24), we obtain

$$\begin{aligned} f_V^2 m_V^2 \exp\left(-\frac{m_V^2}{M^2}\right) &= \int_{4m^2}^{s_0} ds\,[\rho_{t,a}(s)+\rho_{\alpha_s}(s)]e^{-\frac{s}{M^2}} \\ &+ \int_0^{|\mathbf{q}|^2} ds\;\rho_{t,s}(s)e^{-\frac{s}{M^2}} + \widehat{B}\Pi_t^{nonpert}. \end{aligned} \tag{25}$$

As we also previously mentioned, when doing numerical analysis, we will set $|\mathbf{q}| \to 0$. In this case, the scattering cut shrinks to a point and the spectral density becomes a singular function. Hence, the second term in the right side of Eq.(25) must be detailed analyzed. Detailed analysis shows that

$$\lim_{|\mathbf{q}|\to 0} \int_0^{|\mathbf{q}|^2} ds\rho_{t,s}(s)exp\left(-\frac{s}{M^2}\right) = 0. \tag{26}$$

In Eq.(25), $\widehat{B}\Pi_t^{nonpert}$ shows the nonperturbative part of QCD after Borel transformation, which is given by:

Thermal QCD Sum Rules for Vector Mesons

$$\begin{aligned}
\hat{B}\Pi_t^{nonpert} &= \int_0^1 dx \, \frac{1}{144\,\pi\, M^6\, x^4\, (-1+x)^4} \exp\left[\frac{m^2}{M^2\, x\, (-1+x)}\right] \Big\{\langle\alpha_s G^2\rangle \\
\times & \Big[12\, M^6\, x^4\, (-1+x)^4 - m^6\, (1-2x)^2(-1-x+x^2) - 12\, m^2\, M^4\, x^2\, (-1+x)^2 \\
\times & (1-3x+3x^2) + m^4\, M^2\, x\, (-2+19x-32x^2+11x^3+6x^4-2x^5)\Big] + 4\, \alpha_s \langle\Theta^g\rangle \\
\times & \Big[-8\, M^6\, x^3\, (1-2x)^2(-1+x)^3 + m^6\, (1-2x)^2(-1-x+x^2) - 2\, m^2\, M^4\, x^2 \\
\times & (-1+x)^2(-1-6x+8x^2-4x^3+2x^4) + m^4\, M^2\, x\, (-2+3x-12x^2 \\
+ & 31x^3-30x^4+10x^5)\Big]\Big\}, \qquad (27)
\end{aligned}$$

where, $\Theta^g = \Theta^g_{00}$.

Thermal QCD Sum Rules for Vector Mesons

In this section, we discuss the temperature dependence of the masses and leptonic decay constants of the J/ψ and Υ vector mesons. Taking into account the Eqs. (26) and (27) and applying derivative with respect to $1/M^2$ to Eq.(25) and dividing by themselves, we obtain

$$m_V^2(T) = \frac{\int_{4m^2}^{s_0(T)} ds\, s\,[\rho_{t,a}(s) + \rho_{\alpha_s}(s)] \exp\left(-\frac{s}{M^2}\right) + \Pi_1^{nonpert}(M^2,T)}{\int_{4m^2}^{s_0(T)} ds[\rho_{t,a}(s) + \rho_{\alpha_s}(s)] \exp\left(-\frac{s}{M^2}\right) + \widehat{B}\Pi_t^{nonpert}}, \qquad (28)$$

and

$$f_V^2(T) = \frac{1}{m_V^2(T)}\left(\int_{4m^2}^{s_0} ds\,[\rho_{t,a}(s) + \rho_{\alpha_s}(s)]e^{-\frac{s}{M^2}} + \widehat{B}\Pi_t^{nonpert}\right) \exp\left(\frac{m_V^2}{M^2}\right). \qquad (29)$$

where

$$\Pi_1^{nonpert}(M^2,T) = M^4 \frac{d}{dM^2}\widehat{B}\Pi_t^{nonpert}, \qquad (30)$$

and

$$\rho_{t,a}(s) = \frac{1}{8\pi^2} s\nu(s)(3-\nu^2(s))\left[1 - 2n\left(\frac{\sqrt{s}}{2}\right)\right]. \qquad (31)$$

Thermal QCD Sum Rules for Vector Mesons

We use the gluonic part of the energy density both obtained from lattice QCD [20-22] and chiral perturbation theory [19]. The total energy density obtained from lattice QCD [20]is fitted by the following parametrization:

$$\langle\Theta\rangle = 2\langle\Theta^g\rangle = 6\times10^{-6} exp[80(T-0.1)](GeV^4), \tag{32}$$

where temperature T is measured in units of GeV and this parametrization is valid only in the region $0.1\ GeV \leq T \leq 0.17\ GeV$. In chiral perturbation limit, the thermal average of the energy density is expressed as [19]:

$$\langle\Theta\rangle = \langle\Theta^\mu_\mu\rangle + 3\,p, \tag{33}$$

where $\langle\Theta^\mu_\mu\rangle$ is trace of the total energy momentum tensor and p is pressure. These quantities are given by:

Thermal QCD Sum Rules for Vector Mesons

$$\begin{aligned}\langle\Theta^{\mu}_{\mu}\rangle &= \frac{\pi^2}{270}\frac{T^8}{F_\pi^4}\ln\left(\frac{\Lambda_p}{T}\right),\\ p &= 3T\left(\frac{m_\pi\ T}{2\ \pi}\right)^{\frac{3}{2}}\left(1+\frac{15\ T}{8\ m_\pi}+\frac{105\ T^2}{128\ m_\pi^2}\right)exp\left(-\frac{m_\pi}{T}\right),\end{aligned} \tag{34}$$

where $\Lambda_p = 0.275\ GeV$, $F_\pi = 0.093\ GeV$ and $m_\pi = 0.14\ GeV$. Also, we use the temperature dependent continuum threshold $s_0(T)$ [13] and gluon condensate$\langle G^2\rangle$ [20,21] in the following form :

$$s_0(T) = s_0\left[1-\left(\frac{T}{T_c^*}\right)^8\right]+4\ m_Q^2\ \left(\frac{T}{T_c^*}\right)^8, \tag{35}$$

where $T_c^* = 1.1\times T_c = 0.176\ GeV$.

$$\langle G^2\rangle = \frac{\langle 0|G^2|0\rangle}{exp\left[12\left(\frac{T}{T_c}-1.05\right)\right]+1}. \tag{36}$$

Thermal QCD Sum Rules for Vector Mesons

In our calculations, we use the values, $m_c = (1.3 \pm 0.05)\ GeV$, $m_b = (4.7 \pm 0.1)\ GeV$ for quarks masses and $\langle 0 \mid \frac{1}{\pi}\alpha_s G^2 \mid 0 \rangle = (0.012 \pm 0.004)\ GeV^4$ for gluon condensate at zero temperature. The sum rules for the masses and decay constants also include two parametres : continuum threshold s_0 and Borel mass parameter M^2. The continuum threshold, s_0 is not completely arbitrary and it is related to the energy of the first exited state. Our numerical analysis show that in the intervals $s_0 = (11 - 12)\ GeV^2$ for the J/ψ and $s_0 = (98 - 100)\ GeV^2$ for the Υ channels, the results weakly depend on this parameter. The working region for the Borel mass parameter, M^2 is determined demanding that both the contributions of the higher states and continuum are sufficiently suppressed and the contributions coming from the higher dimensional operators are small. As a result, the working region for the Borel parameter is found to be $8\ GeV^2 \leq M^2 \leq 25\ GeV^2$ for J/ψ and $12\ GeV^2 \leq M^2 \leq 35\ GeV^2$ for Υ mesons.

Thermal QCD Sum Rules for Vector Mesons

Firstly, we calculated the values of the decay constants of the J/ψ and Υ mesons at $T = 0$ and we obtained that $f_{J/\psi} = (460 \pm 22)\ MeV$ and $f_{\Upsilon} = (715 \pm 32)\ MeV$. These results are in good consistency with the existing experimental data and predictions of the other nonperturbative models [25,26]. Finally, we plot the temperature dependence of the decay constants and masses in figures 2-5 at different values of the s_0. As shown in these graphs, decay constants and masses remain insensitive to the variation of the temperature up to $T \cong 100\ MeV$, however after this point, they start to diminish increasing the temperature.At deconfinement or critical temperature, the decay constants approach roughly to 50% of their values at zero temperature, while the masses are decreased about 12%, and 2.5% for J/ψ and Υ mesons, respectively. Our results at zero temperature as well as the behavior of the mass and decay constant with respect to the temperature can be checked in the future experiments. Also the temperature dependence of the considering quantities can be used in analysis of the heavy ion collision experiments.

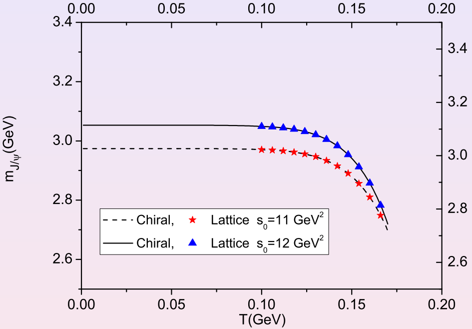

Figure: 2.The dependence of the mass of J/ψ vector meson in GeV on temperature at $M^2 = 10\ GeV^2$.

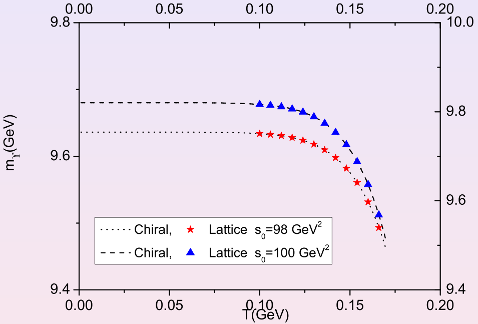

Figure: 3.The dependence of the mass of Υ vector meson in GeV on temperature at $M^2 = 20\ GeV^2$.

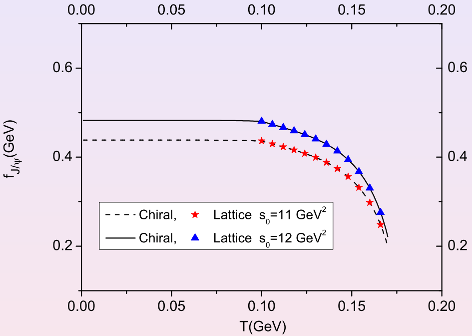

Figure: 4.The dependence of the leptonic decay constant of J/ψ vector meson in GeV on temperature at $M^2 = 10\ GeV^2$.

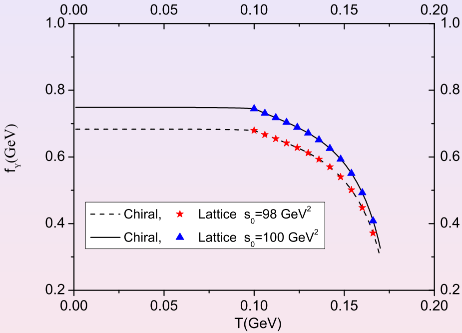

Figure: 5.The dependence of the leptonic decay constant of Υ vector meson in GeV on temperature at $M^2 = 20\ GeV^2$.

Acknowledgement

This work is supported by the Scientific and Technological Research Council of Turkey (TUBITAK), research project no.110T284.

References

- [1] M. A. Shifman, A. I. Vainstein, V. I. Zakharov, Nucl. Phys. *B147*, 385 (1979); M. A. Shifman, A. I. Vainstein, V. I. Zakharov, Nucl. Phys. *B147*, 448 (1979).
- [2] T. Matsui, H. Satz, Phys. Lett. *B178*, 416 (1986).
- [3] L. J. Reinders, H. Rubinstein and S. Yazaki, Phys. Rep. *127*, No1 (1985) 1.
- [4] P. Colangelo, A. Khodjamirian, in At the Frontier of Particle Physics/Handbook of QCD, edited by M. Shifman (World Scientific, Singapore, 2001), Vol. 3, p. 1495.
- [5] A. I. Bochkarev, M. E. Shaposhnikov, Nucl. Phys. *B268*, 220, (1986).
- [6] E.V. Shuryak, Rev. Mod. Phys. 65, 1 (1993).
- [7] T. Hatsuda, Y. Koike, S.H. Lee, Nucl. Phys. *B394*, 221 (1993).
- [8] S. Mallik, Phys. Lett. *B416*, 373 (1998).
- [9] S. Mallik, K. Mukherjee, Phys. Rev. *D58*, 096011 (1998); Phys. Rev. *D61*, 116007 (2000).
- [10] S. Mallik, S. Sarkar, Phys.Rev. *D66*, 056008 (2002).

References

- [11] E. V. Veliev, J. Phys. G:Nucl. Part. Phys., *G35*, 035004 (2008); E. V. Veliev, T. M. Aliev, J. Phys. G:Nucl. Part. Phys., *G35*, 125002 (2008).
- [12] C.A. Dominguez, M. Loewe, J.C. Rojas, JHEP 08, 040 (2007).
- [13] C. A. Dominguez, M. Loewe, J.C. Rojas, Y. Zhang, Phys. Rev. *D81*, 014007 (2010).
- [14] E. V. Veliev, G. Kaya, Eur. Phys. J. *C63*, 87 (2009); Acta Phys. Polon. *B41*, 1905 (2010).
- [15] F. Klingl, S. Kim, S.H. Lee, P. Morath and W. Weise, Phys. Rev. Lett. 82, (1999).
- [16] K. Morita, S.H. Lee, Phys. Rev. *C77*, 064904 (2008).
- [17] K. Morita, S.H. Lee,Phys. Rev. *D82*, 054008 (2010).
- [18] E. V. Veliev, H. Sundu, K. Azizi, M. Bayar, Phys. Rev. *D82*, 056012 (2010); E. V. Veliev, K. Azizi, H. Sundu, N. Akşit, arXiv:1010.3110 [hep-ph].
- [19] P. Gerber, H. Leutwyler, Nucl. Phys. *B321*, 387 (1989).

References

- [20] M. Cheng, et.al, Phys. Rev. *D77*, 014511 (2008).
- [21] D. E. Miller, Phys. Rept. *443*, 55 (2007).
- [22] O. Kaczmarek, F. Karsch, F. Zantow, P. Petreczky, Phys. Rev. *D70*, 074505 (2004).
- [23] R. L. Kobes, G.W. Semenoff, Nucl. Phys. *260*, 714 (1985), S. Sarkar, B. K. Patra, V. J. Menon, S. Mallik, Indian J. Phys. *76A*, 385 (2002)
- [24] A. Das, Finite Temperature Field Theory, World Scientific (1999).
- [25] V. V. Kiselev, A. K. Likhoded, O. N. Pakhomova, V. A. Saleev, Phys. Rev. *D65*, 034013(2002).
- [26] O. Lakhina, E. S. Swanson, Phys. Rev. *D74*, 014012 (2006).
- [27]K. Nakamura et al. (Particle Data Group), J. Phys. *G37*, 075021 (2010).

THANKS !

⋆ ⋆ ⋆ ⋆ ⋆ ⋆ ⋆⋆
⋆ ⋆ ⋆ ⋆ ⋆ ⋆ ⋆⋆
⋆ ⋆ ⋆ ⋆ ⋆ ⋆ ⋆⋆
⋆ ⋆ ⋆ ⋆ ⋆ ⋆ ⋆⋆
⋆ ⋆ ⋆ ⋆ ⋆ ⋆ ⋆⋆
⋆ ⋆ ⋆ ⋆ ⋆ ⋆ ⋆⋆
⋆ ⋆ ⋆ ⋆ ⋆