Meson-Δ and Meson-Nucleon-Δ Transition Coupling Constants in the Soft-Wall Model of Holographic QCD at Finite Temperatures

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Abstract

In this paper, minimal coupling constants of meson-Δ baryon and meson-nucleon to Δ baryon transition have been investigated in the AdS/QCD soft-wall model at finite temperature limits. Initially, the right and left profile functions of Δ baryons have been calculated using the Rarita-Schwinger field in this model. After this, the expressions of coupling constants have been written by considering the profile functions of thermal hadrons according to the zero-temperature case of expressions. Then, the temperature dependence graphs have been plotted for strong couplings $g_{\rho\Delta\Delta}(T)$, $g_{a_1\Delta\Delta}(T)$, and $g_{\rho N\Delta}(T)$. As a result, it was observed that the values of minimal coupling constants decrease with increasing temperature and approach zero near the Hawking temperature.

Keywords: AdS/CFT, holographic duality, soft-wall model, meson, baryon, coupling constant
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1. INTRODUCTION

One notable application of string theory is the anti-de Sitter/conformal field theory (AdS/CFT) [1, 2, 3, 4, 5] or holographic duality, which is used to study the coupling regime of quantum field theories. This theory is also called gravity/gauge duality. This principle is based on closed and open string duality according to the relationship between the open and closed strings. As such, in this principle, the gravitational field corresponding to the closed string is defined by the boundary, and the field theory corresponds to the open string by the bulk of the AdS space. QGP (Quark-Gluon Plasma), condensed matter systems, and other QCD problems are impossible to solve by using perturbation theory; however, they can be studied by using the methods of this duality. The duality between gravitational and gauge theories is the strong-weak duality, which also was adapted to describe the low- and high-energy dynamics of QCD (Quantum Chromodynamics). Investigating hadron interaction processes in the nuclear medium in proton-proton and heavy ion collisions in order to study the phase transition of QGP and the evolution of the early Universe is also a very important issue. Such problems are solved using AdS/QCD or holographic QCD models. AdS/QCD which was created based on this duality has two hard- and soft-wall models for modifying the metric in the AdS space-time. These models are widely applied in particle physics for quantifying phenomenological prediction quantities and investigating other strong interaction problems.

In theoretical physics, many QCD problems were solved by holographic QCD models in the vacuum and low-temperature medium in [6, 7, 8, 9, 10, 11, 12, 13, 14]. The derivation of analytical formulas for the mass spectrum of mesons and Δ baryons and their coupling constants has been investigated in [15, 16]. In addition, reasonable results have been found for the transition and electromagnetic form factors of nucleons in the soft-wall model of holographic QCD at finite temperatures. Continuing these investigations in [17], we have studied the temperature dependence of vector meson coupling constant in the soft-wall model of AdS/QCD. It was observed that the coupling constant of ρ vector meson decreases when temperature increases and vanishes at the temperature close to the confinement-deconfinement phase transition temperature.

It is interesting to check whether this situation takes place for other meson sectors of the model as well. As a continuation of [17], we have decided to study, for simplicity, the minimal coupling constant of meson-baryon and meson-nucleon to Δ baryon transitions based on the case reviewed in [18] at finite temperatures. Our aim here is to study temperature dependence in the spectrum of spin 3/2 baryons (Δ resonances) and the coupling constants between mesons and baryons in the soft-wall model of holographic QCD at finite temperatures.

The remainder of this paper is organized as follows. Sections 2 and 3 are about the soft-wall model and the breaking of chiral symmetry at finite temperatures. In Section 4, the profile functions of Δ baryons have been obtained at finite temperatures in the bulk of AdS space-time. In Section 5, we construct the Lagrangian for the vector-spinor interaction in the bulk and obtain the temperature-dependent integral expression for the minimal coupling constants of $g_{\rho\Delta\Delta}(T)$, $g_{a_1\Delta\Delta}(T)$, and $g_{\rho N\Delta}(T)$ using holographic correspondence at the boundary of QCD. In Section 6, the free parameters are fixed and the graphs of strong coupling constants are plotted at the different values of the quark flavor parameter N_f. The last section is devoted to discussion and conclusions.

2. THERMAL SOFT-WALL MODEL OF HOLOGRAPHIC QCD

The Schwarzschild metric can be written as follows [15]:

$$ds^2 = e^{2A(z)}\left[f(z)dt^2 - (d\vec{x})^2 - \frac{dz^2}{f(z)}\right], \quad f(z) = 1 - \frac{z^4}{z_H^4}. \quad (1)$$

The relation between tortoise coordinates r and z is as follows:

$$r = \int \frac{dz}{f(z)}. \quad (2)$$

In the finite temperature limit, the r coordinate can be expanded as

$$r \approx z\left[1 + \frac{z^4}{5z_H^4} + \frac{z^8}{9z_H^8}\right]. \quad (3)$$

So, the AdS-Schwarzschild space-time metric in the Regge-Wheeler (RW) tortoise coordinate r [15] will be written as follows:

$$ds^2 = e^{2A(r)} f^{\frac{3}{5}}(r) \left[dt^2 - \frac{(d\vec{x})^2}{f(r)} - dr^2 \right]. \tag{4}$$

Here, $A(r) = \log(\frac{R}{r})$ and the thermal factor $f(r)$ has the following form:

$$f(r) = 1 - \frac{r^4}{r_H^4}, \tag{5}$$

where r_H is the position of the event horizon. It is related to the Hawking temperature as $T = 1/(\pi r_H)$, $x = (t, \vec{x})$ is the set of Minkowski coordinates, $A(r) = \log(\frac{R}{r})$, and R is the AdS space radius. k is a scale parameter.

The AdS-Schwarzchild geometry is more suitable at high T, while at small T this metric can be also used by making a small T-expansion. The limit $T = 0$ corresponds to a mapping of the AdS-Schwarzchild geometry onto AdS Poincare metric, and the small T-the behavior of hadron properties can be generated in the formalism based on AdS Poincare metric and with the use of a thermal dilaton. It leads to equivalent results: AdS-Schwarzchild geometry with small T is equal to AdS Poincare metric with thermal dilaton.

The dilaton field φ has the following form:

$$\varphi(r, T) = K^2(T) r^2, \tag{6}$$

where

$$K^2(T) = k^2 \left[1 + \rho(T)\right]. \tag{7}$$

So, $K^2(T)$ is the parameter in the spontaneous breaking of chiral symmetry, while the thermal function $\rho(T)$ up to T^4 order has the following form:

$$\rho(T) = \delta_{T_1} \frac{T^2}{12F^2} + \delta_{T_2} \left(\frac{T^2}{12F^2} \right)^2. \tag{8}$$

Here, F is the decay constant, and there is the relation between the coefficients δ_{T_1} and δ_{T_2} and quark flavors N_f

$$\delta_{T_1} = -\frac{N_f^2 - 1}{N_f}, \tag{9}$$

$$\delta_{T_2} = -\frac{N_f^2 - 1}{2N_f^2}. \tag{10}$$

3. CHIRAL SYMMETRY BREAKING AT FINITE TEMPERATURES

In AdS/CFT correspondence, the currents in the boundary will correspond to the bulk gauge fields at finite temperatures. The scalar field X transforms as a bifundamental under the $SU(2)_L \times SU(2)_R$ group. The five-dimensional mass $M_5^2 = \Delta_0(\Delta_0 - 4)$ of the scalar which is fixed with the scaling dimension Δ_0. The solution for the bulk scalar X at finite temperatures is defined as $\chi(r, T) \approx \frac{1}{2} a m_q r + \frac{1}{2a} \Sigma(T) r^3 = \vartheta(r, T)$, where the mass of quarks is m_q, $\Sigma(T)$ is the value of thermal chiral condensate, and $a = \frac{\sqrt{N_c}}{2\pi}$. The conventions are the fact that the temperature dependence of $\Sigma(T)$ quark condensate is defined as $\Sigma(T) = \Sigma[1 + \Delta_T]$ and $\Sigma(T) = \langle 0|\bar{q}q|0\rangle_T = -N_f B(T) F^2(T)$ [28]. In the chiral limit, N_f is the number of quark flavors, $B(T)$ is the quark condensate parameter, and $F(T)$ is the pseudoscalar meson decay constant in the chiral limit at finite temperatures. $F(T)$ and $B(T)$ have been studied and calculated in [19].

4. MESON FIELDS AT FINITE TEMPERATURES

In this section, the author derives the results of the meson-baryon coupling constants of hadrons at low temperatures. First, the author calculates the meson profile function at low temperatures using the universal action derived in [15]. The corresponding EOM (Equation of Motion) for the Fourier transform of the bulk-to-boundary profile function of mesons $\phi_n(r, T)$ in Euclidean metric is as follows:

$$\left[-\frac{d^2}{dr^2} + U(r, T) \right] \phi_n(r, T) = M_n^2(T) \phi_n(r, T). \tag{11}$$

$U(r, T)$ is the effective potential and consists of the temperature-dependent and nondependent parts:

$$U(r, T) = U(r) + \Delta U(r, T). \tag{12}$$

Explicit forms of the $U(r)$ and $\Delta U(r, T)$ terms were given as

$$U(z) = k^4 r^2 + \frac{(4m^2 - 1)}{4r^2}, \tag{13}$$

$$\Delta U(r, T) = 2\Delta(T) k^4 r^2. \tag{14}$$

The meson mass spectrum M_n^2 is shown in the following form by the sum of zero and finite temperature parts:

$$M_n^2(T) = M_n^2(0) + \Delta M_n^2(T), \tag{15}$$

$$\Delta M_n^2(T) = \rho(T) M_n^2(0) + \frac{R \pi^4 T^4}{k^2}, \tag{16}$$

$$M_n^2(0) = 4k^2 \left(n + \frac{m+1}{2} \right), \tag{17}$$

where $R = (6n - 1)(m + 1)$.

In the low-temperature case, the hadronic mass spectrum is

$$M_n^2(T) = M_n^2(0) + \Delta M_n^2(T), \tag{18}$$

$$\Delta M_n^2(T) = \rho_T M_n^2(0) + \frac{R \pi^4 T^4}{k^2}, \quad R = (6n - 1)(m + 1). \tag{19}$$

The profile function of mesons in general form is given [15] as follows:

$$\phi_n(r, T) = \sqrt{\frac{2\Gamma(n+1)}{\Gamma(n+m+1)}} K(T)^{m+1} r^{m+\frac{1}{2}} e^{-\frac{K(T)^2 r^2}{2}} L_n^m \left(K(T)^2 r^2 \right). \tag{20}$$

For the meson with two quarks $m = L$. By taking $m = 1$ for the vector and axial vector mesons, we have replaced $\phi_n(r, T)$ by $M_0(r, T)$ as the meson profile function in the expression of the coupling constant.

5. RARITA-SCHWINGER FIELDS AT FINITE TEMPERATURES

According to the principle of holographic duality, the fields set against the Δ baryon operators and the nucleon operator with a defined spin 1/2 at the boundary of the AdS space-time differ from each other. Thus, while the Dirac field corresponds to nucleons with spin 1/2, the Δ baryon operators with spin 3/2 are opposed to the Rarita-Schwinger fields Ψ_M within this space-time [20, 21, 22, 23]. The action for the Rarita-Schwinger field at finite temperatures can be written corresponding to zero-temperature case as follows:

$$\int d^5x\sqrt{G}\left(i\bar{\Psi}_A\Gamma^{ABC}D_B\Psi_C - m_1\bar{\Psi}_A\Psi^A - m_2\bar{\Psi}_A\Gamma^{AB}\Psi_B\right), \tag{21}$$

where $\Psi_A = e^M_A\Psi_M$, and we used notations $\Gamma^{ABC} = \frac{1}{3!}\Sigma_{\text{perm}}(-1)^p\Gamma^A\Gamma^B\Gamma^C = \frac{1}{2}(\Gamma^B\Gamma^C\Gamma^A - \Gamma^A\Gamma^C\Gamma^B)$ and $\Gamma^{AB} = \frac{1}{2}[\Gamma^A, \Gamma^B]$. The Rarita-Schwinger equations in AdS_5 are written as

$$i\Gamma^A\left(D_A\Psi_B - D_B\Psi_A\right) - m_-\Psi_B + \frac{m_+}{3}\Gamma_B\Gamma^A\Psi_A = 0, \tag{22}$$

where $m_\pm = m_1 \pm m_2$. m_1 and m_2 correspond to those of spinor harmonics on S^5 of $AdS_5 \times S^5$ [24].

As is well known, the Rarita-Schwinger field contains the states of the field with spin 1/2 in addition to spin 3/2 components. In 4-dimensional space, the components with spin 1/2 are eliminated by imposing the Lorentz condition on this field:

$$\gamma^\mu\Psi_\mu = 0. \tag{23}$$

The following Lorentz-covariant constraint will project out one of the spin-1/2 components from the Rarita-Schwinger fields in a five-dimensional space corresponding to a four-dimensional space.

$$e^M_A\Gamma^A\Psi_M = 0, \tag{24}$$

which then gives $\partial^M\Psi_M = 0$ for a free particle if combined with equations of motion.

This field has extra spin-1/2, Ψ_z, if decreased to four-dimensional space-time at finite temperatures. By choosing $\Psi_r = 0$, it is possible to reduce the extra spin-1/2 degrees of freedom, because there is no extra spinor at finite temperatures.

$$\left(iz\Gamma^A\Psi_A + 2i\Gamma^5 - m_-\right)\Psi_\mu = 0 \quad (\mu = 0,1,2,3), \tag{25}$$

$$\Psi_{M(R)} = \frac{1}{2}\left(1+\gamma^5\right)\Psi_{NE}, \tag{26}$$

$$\Psi_{M(L)} = \frac{1}{2}\left(1-\gamma^5\right)\Psi_M, \tag{27}$$

$$\left[\partial_r^2 - \frac{2\left(m_- + K(T)^2r^2\right)}{r}\partial_r + \frac{2\left(m_- - K(T)^2r^2\right)}{r^2} + p^2\right]\Psi_L = 0, \tag{28}$$

$$\left[\partial_r^2 - \frac{2\left(m_- + K(T)^2r^2\right)}{r}\partial_r + p^2\right]\Psi_R = 0. \tag{29}$$

The solution of these equations with the polynomial is similar to the fermion field, as follows:

$$f^L_n(r,T) = \sqrt{\frac{2\Gamma(n+1)}{\Gamma\left(n+m_L+1\right)}}K^{m_L+1}r^{m_L+\frac{1}{2}}e^{-\frac{K^2r^2}{2}}L^{m_L}_n\left(K^2r^2\right),$$
$$f^R_n(r,T) = \sqrt{\frac{2\Gamma(n+1)}{\Gamma\left(n+m_R+1\right)}}K^{m_R+1}r^{m_R+\frac{1}{2}}e^{-\frac{K^2r^2}{2}}L^{m_R}_n\left(K^2r^2\right), \tag{30}$$

where $m_{L,R} = m \pm \frac{1}{2}$. To describe the spin 3/2 baryons (Δ resonances) in the soft-wall model at finite temperatures, one has to introduce a pair of Rarita-Schwinger fields in the bulk, Ψ^A_1 (for the left-handed spin-3/2) and Ψ^A_2 (for the right-handed spin-3/2), which obey the above Rarita-Schwinger equations. The author has considered [14] to describe the spin 1/2 baryons (nucleons) profile functions in the soft-wall model at a finite temperature which obeys the Dirac equation in the bulk [16]. The left-handed spin-1/2 baryon profile function is given by $F^A_1(r,T)$, whenever the right-handed spin-1/2 baryon is given by $F^A_2(r,T)$. Note that the profile functions of spin 1/2 and 3/2 baryon are the same in a certain approximation. The profile functions of Δ baryon $f_m(r,T)$ and nucleon $F_n(r,T)$ obey normalization conditions as

$$\int_0^\infty dr e^{-\frac{3}{2}A(r)}f^{L,R}_m(r,T)F^{L,R}_n(r,T) = \delta_{mn}. \tag{31}$$

6. STRONG COUPLING CONSTANTS $G_{\rho\Delta\Delta}(T)$, $G_{A_1\Delta\Delta}(T)$, AND $G_{\rho N\Delta}(T)$ AT FINITE TEMPERATURES

In this section, the author is interested in the properties of Δ resonances in AdS/QCD at finite temperatures. The resonance to nucleons of Δ baryons is very necessary for the study of nucleon potential, as the decay channel of Δ resonance at finite temperatures. Generally, the interaction Lagrangian is constructed based on the gauge invariant of the model and contains a term of minimal gauge interaction of the meson field with the fermions corresponding zero-temperature limit [18]. Meson-baryon transition coupling constants have been obtained from the action by including the thermal dilaton field in the action.

The thermal couplings have expressions of thermal profile functions of the bulk fields. It has calculated the terms of thermal action in the momentum space and taken the variation derivative from Lagrangian terms. This variation gives us the following contribution of each Lagrangian term to the nucleon current.

The minimal Lagrangian term of π meson is as follows:

$$\mathcal{L}_{\pi\Delta\Delta} = \bar{\Psi}^\mu_1\Gamma^rA_r\Psi_{1\mu} - \bar{\Psi}^\mu_2\Gamma^rA_r\Psi_{2\mu}. \tag{32}$$

Here, Γ is Dirac matrices in the reference frame. Γ^r matrices are chosen as $\Gamma^r = (\gamma^\mu, -i\gamma^5)$. The expressions $\Psi^\sigma_{L,R}(p,r) = \sum_n F^{(n)}_{L,R}(p,r)\psi^{(n)\sigma}_{L,R}(p)$ are spinors for the five-dimensional AdS space.

So, by making some calculations, the temperature dependence expression of the π meson Δ baryon coupling constant is obtained from the minimal Lagrangian $\mathcal{L}_{\pi\Delta\Delta}$ term which corresponds to the π meson Δ baryon coupling constant at zero-temperature.

The π meson Δ baryon coupling constant $g^{(0)nm}_{\pi\Delta\Delta}(T)$ has the following form:

$$g^{(0)nm}_{\pi\Delta\Delta}(T) = -\int_0^\infty \frac{dr}{2r^2}\left[M_0(r,T)\left(f^{(n)*}_{1L}(r,T)f^{(m)}_{1R}(r,T) - f^{(n)*}_{2L}(r,T)f^{(m)}_{2R}(r,T)\right)\right]. \quad (33)$$

The Lagrangian of ρ meson-Δ baryon interaction $\mathcal{L}_{\rho\Delta\Delta}$ is as follows [25]:

$$\mathcal{L}_{\rho\Delta\Delta} = \bar{\Psi}^\nu_1\Gamma^\mu V_\mu \Psi_{1\nu} + \bar{\Psi}^\nu_2\Gamma^\nu V_\nu \Psi_{2\nu}. \quad (34)$$

From its corresponding Lagrangian, the ρ meson Δ baryon coupling constant $g^{(0)nm}_{\rho\Delta\Delta}(T)$ has the following form:

$$g^{(0)nm}_{\rho\Delta\Delta}(T) = -\int_0^\infty \frac{dz}{r^2}M_0(r,T)\left[\left(f^{(n)*}_{1L}(r,T)f^{(m)}_{1L}(r,T) + f^{(n)*}_{2L}(r,T)f^{(m)}_{2L}(r,T)\right)\right]. \quad (35)$$

a_1 meson Δ baryon coupling constant arises from the bulk gauge coupling constant [26], and the minimal interaction Lagrangian terms have the following form:

$$\mathcal{L}_{a_1\Delta\Delta} = \bar{\Psi}^M_1 e^M_A \Gamma^M A_M \Psi_{1M} - \bar{\Psi}^M_2 e^M_A \Gamma^M A_M \Psi_{2M}, \quad (36)$$

and the magnetic gauge interaction or Pauli terms $\mathcal{L}_{a_1\Delta\Delta}$ is as follows:

$$\mathcal{L}_{a_1\Delta\Delta} = k_1\bar{\Psi}^M_1 e_A e^N_B \Gamma^{MN}F_{MN}\Psi_{1M} - \bar{\Psi}^M_2 e^M_A e^N_B \Gamma^{MN}F_{MN}\Psi_{2M}. \quad (37)$$

Thus, after making certain simplifications, we obtain from the minimum interaction Lagrangian terms a_1 meson Δ baryon minimal coupling constant $g^{(0)nm}_{a_1\Delta\Delta}(T)$ in the framework of the soft-wall framework which can be written as

$$g^{(0)nm}_{a_1\Delta\Delta}(T) = \int_0^\infty \frac{dr}{r^2}M_0(r,T)\left(f^{(n)}_{1R}(r,T)^2 - f^{(m)}_{1L}(r,T)^2\right). \quad (38)$$

$M_0(r,T)$ is the expression of the profile function or wave function of the a_1 meson in the ground state. The additional contributions to $g^{(1)nm}_{a_1\Delta\Delta}(T)$ coupling constant can arise from the magnetic type of interaction in the bulk of AdS space-time as the following form:

$$g^{(1)nm}_{a_1\Delta\Delta}(T) = \frac{k_1}{2}\int_0^\infty \frac{dr}{r^2}M_0'(r,T)\left(f^{(n)}_{1L}(r,T)^2 + f^{(n)}_{1L}(r,T)^2\right). \quad (39)$$

The π meson transition coupling constant has been obtained from the gauge-invariant coupling constant of gauge fields with Δ resonances and nucleons at finite temperatures. The Lagrangian for these fields is given by

$$\mathcal{L}_{FN\Delta} = \left[\alpha_1\left(\bar{\Psi}^M_1\Gamma^N(F_L)_{MN}N_1 - (1\leftrightarrow 2,\ L\leftrightarrow R)\right)\right], \quad (40)$$

where α_1 is a parameter [18]. The terms contribute to the 4D ρ meson thermal coupling constant. By KK reduction of 5D spinors as $\Psi_{iL,R}(p,r) = \sum_n f^{(n)}_{iL,R}(p,r)\psi^{(n)}_{L,R}(p)$ for nucleons and $\Psi_{L,R}(p,r) = \sum_n F^{(n)}_{L,R}(p,r)\psi^{(n)}_{L,R}(p)$ for Δ resonances, one can write the pion-nucleon-Δ couplings as

$$g^{nm}_{\pi N\Delta}(T) = -f_\pi\int_0^\infty dr\left[\frac{M_0(r,T)}{r^2}\left(\kappa\left(F^{(n)*}_{1L}(r,T)f^{(m)}_{1R}(r,T) + F^{(n)*}_{2L}(r,T)f^{(m)}_{2R}(r,T)\right)\right)\right], \quad (41)$$

and similarly the rho-nucleon-Δ couplings at finite temperatures as

$$g^{nm}_{\rho N\Delta}(T) = \int_0^\infty dr\left[\frac{M_0(r,T)}{r^2}\left(\kappa\left(F^{(n)*}_{1L}(r,T)f^{(m)}_{1R}(r,T) - F^{(n)*}_{2L}(r,T)f^{(m)}_{2R}(r,T)\right)\right)\right]. \quad (42)$$

7. NUMERICAL RESULTS

The coupling constants at finite temperatures $g_{\rho\Delta\Delta}(T)$, $g_{a_1\Delta\Delta}(T)$, and $g_{\rho N\Delta}(T)$ consist in the numerical calculation of the integrals and in numerically plotting their temperature dependencies by means of the Mathematical package. The author presents numerical results for the parameters $N_f = 2$, $F = 87$ MeV, $N_f = 3$, $F = 100$ MeV, $N_f = 4$, $F = 130$ MeV, and flovour $N_f = 5$, $F = 140$ MeV. These sets of parameters were taken from [18]. There are free parameters k, k_1, m_q, and Σ in this work. The value of parameter $k = 383$ MeV [15] and parameter $\bar{k} = -733$ [18]. The parameters k_1 are fixed at the values $k_1 = -0.78\,\text{GeV}^3$ in the [26]. The $\Sigma = 0.368^3\,\text{MeV}^3$ value and the $m_q = 0.0023$ GeV value of these parameters were found from the fitting of the π meson mass [27]. Having an idea of the relative contributions of different flavors of hadrons, the author presents results for the temperature dependencies of the various numbers separately.

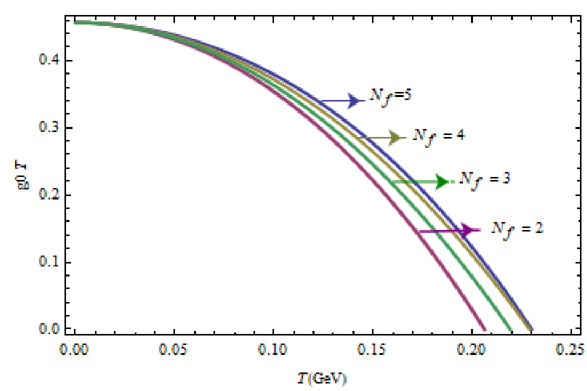

FIGURE 1: The temperature dependence of $g^0_{\rho\Delta\Delta}(T)$ for $N_f = 2$, $F = 87$ MeV, $N_f = 3$, $F = 100$ MeV, $N_f = 4$, $F = 130$ MeV, $N_f = 5$, $F = 140$ MeV.

The ρ meson Δ baryon coupling constant $g^0_{\rho\Delta\Delta}(T)$ (shown in Figure 1), the a_1 meson Δ baryon coupling constant $g^0_{a_1\Delta\Delta}(T)$ (shown in Figure 2), and the ρ meson-nucleon-Δ -transition coupling constant $g_{\rho N\Delta}(T)$ (shown in Figure 4) were plotted at the parameter $N_f = 2$, $F = 87$ MeV, $N_f = 3$, $F = 100$ MeV,

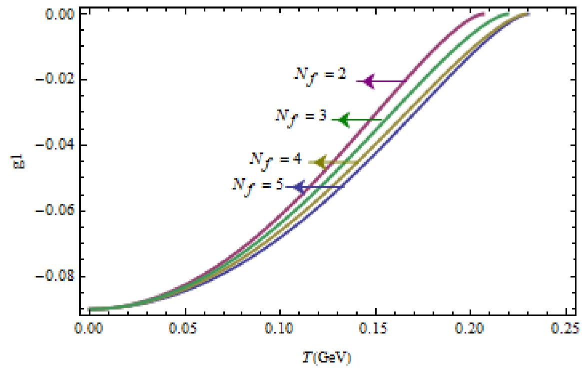

FIGURE 2: The temperature dependence of $g^0_{a_1\Delta\Delta}(T)$ for $N_f = 2$, $F = 87\,\text{MeV}$, $N_f = 3$, $F = 100\,\text{MeV}$, $N_f = 4$, $F = 130\,\text{MeV}$, $N_f = 5$, $F = 140\,\text{MeV}$.

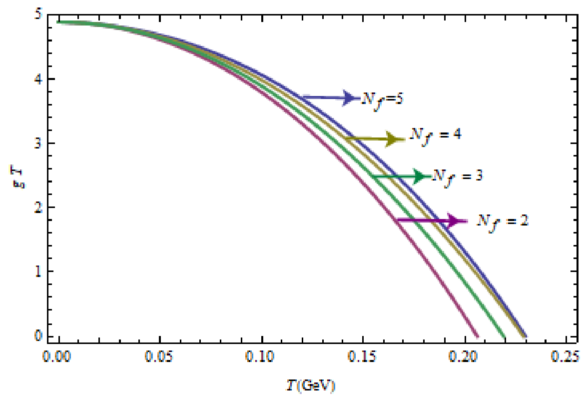

FIGURE 3: The temperature dependence of $g^1_{a_1\Delta\Delta}(T)$ for $N_f = 2$, $F = 87\,\text{MeV}$, $N_f = 3$, $F = 100\,\text{MeV}$, $N_f = 4$, $F = 130\,\text{MeV}$, $N_f = 5$, $F = 140\,\text{MeV}$.

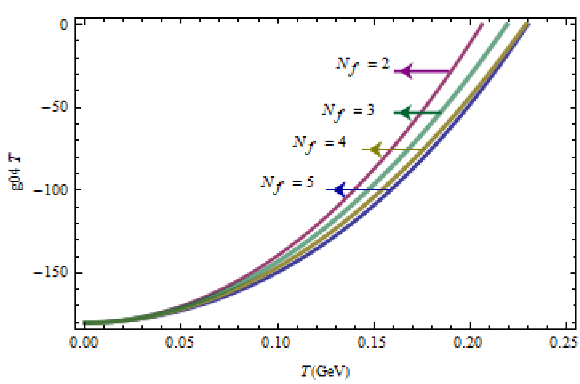

FIGURE 4: The temperature dependence of $g_{\rho N\Delta}(T)$ for $N_f = 2$, $F = 87\,\text{MeV}$, $N_f = 3$, $F = 100\,\text{MeV}$, $N_f = 4$, $F = 130\,\text{MeV}$, $N_f = 5$, $F = 140\,\text{MeV}$.

$N_f = 4$, $F = 130\,\text{MeV}$, and $N_f = 5$, $F = 140\,\text{MeV}$. In Figure 3, the author also has considered these dependencies for $g^1_{a_1\Delta\Delta}(T)$ of the nucleons and drawing graphs for the different number of flavors. The purple graph curve represents two $N_f = 2$, $F = 87\,\text{MeV}$, the green curve shows the three $N_f = 3$, $F = 100\,\text{MeV}$, the orange curve shows the four $N_f = 4$, $F = 130\,\text{MeV}$, and blue one shows the five flavors $N_f = 5$, $F = 140\,\text{MeV}$ of thermal minimal coupling constants in the figures. This analysis shows a weak dependence on the parameter N_f of the coupling constants [29].

8. SUMMARY

In the present work, the author studies the temperature dependency of minimal coupling constants of meson-Δ baryon and meson-nucleon to Δ baryon transition in the framework of the soft-wall model of holographic QCD. It has been observed that the value of all terms becomes zero at the same point near the Hawking temperature by increasing temperature. The minimal coupling constants of meson-Δ baryon and meson-nucleon to Δ baryon transition may be of use in the deeper study of the nucleon-delta baryon transition and in understanding processes of the early Universe.

CONFLICTS OF INTEREST

The author declares that there are no conflicts of interest regarding the publication of this paper.

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