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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

STUDY OF HADRON INTERACTIONS AT FINITE TEMPERATURE lN HOLGRAPHIC QUANTUM CHROMODYNAMICS

Specialty: 2212.01-Theoretical Physics

Field of science: Physics

Applicant: **Narmin Alimammad Nasibova**

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The dissertation work was perfomed at the Institute of Physics of the Ministry of Education and Science, laboratory "Nuclear and High Energy Physics".

Scientific supervisor: Candidate of Physical and Mathematical Sciences, Associate Professor
Shahin Alisattar Mamedov

Official Opponents: Doctor of physics-Mathematics Sciences, Professor
Tahmasib Mammad Aliyev

Corresponding member of ANAS
Doctor of Physics-Mathematics Sciences, Professor
Salima Ibrahim Mehdiyeva

Candidate of Physical and Mathematical Sciences, Associate Professor
Mamed Rajab Rajabov

Dissertation Council ED 2.19 of the Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Baku State University

Chairman of the
Dissertation Council: Doctor of Physics Sciences, Associate Professor
_______________ **Huseyn Mikayil Mammadov**

Scientific secretary of the
Dissertation Council: Candidate of Physical Sciences
_______________ **Shahla Nabi Hacıyeva**

Chairperson of the
Scientific Seminar: Doctor of Physics-Mathematics Sciences, Professor
_______________ **Sarhaddin Qubaddin Abdullayev**

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GENERAL DESCRIPTION OF THE WORK

Actuality of the work and work done so far. Scientific research conducted on the high-density nuclear medium resulting from the collision of heavy ions is one of the current research areas in high-energy physics. The collision of heavy ions leads to the creation of various hadrons. These created hadrons interact with each other and with the nucleons forming the medium. Unlike electromagnetic interaction, the strong interaction processes of hadrons cannot be described with the perturbation theory in any energy range. This is because the strong coupling constant is sufficiently large in the low-energy range. Therefore, non-perturbation methods should be used to study such issues. One of these methods is holographic quantum theory. Holographic theories are based on the principle of holographic correspondence. According to the holographic correspondence principle, there is correspondence between the gravity theory in the 5-dimensional Anti-de-Sitter (AdS) space and the gauge field theory (CFT) on the boundary of this space in 4 dimensions. Holographic correspondence models and theories are applied not only in the physics of elementary particles but also in many areas of theoretical physics, including the theory of condensed matter. Also, by considering the temperature of the hadron medium through holographic quantum chromodynamics (QCD), it is possible to study the strong interaction processes of hadrons. Studying the temperature dependence of these processes is set as the goal within the framework of the dissertation. In the dissertation, some issues of strong interaction are theoretically analyzed by applying models based on the holographic correspondence principle. In addition, the investigation of the properties of the hadron medium is also possible within the framework of holographic theory. Models built on this theory allow calculating strong interaction issues in the 5-dimensional AdS space by preserving properties such as the breaking of chiral symmetry and confinement in the existing 4-dimensional space.

Based on holographic theory, the AdS/QCD (Anti-de-Sitter/Quantum Chromodynamics) model is actionive for addressing issues such as the study of strongly interacting quark-gluon plasmas, including the calculation of strong coupling constants and form factors of hadrons, as well as understanding temperature dependence. The strong coupling constants and form factors of hadrons have been calculated theoretically based on the QCD formalism and other models, and their temperature dependencies have also been studied. Investigating the temperature dependence of the coupling of various hadrons allows for a clearer understanding of phase transitions occurring in the evolution of the Universe and in quark-gluon plasmas. Additionally, comparing the temperature dependence of these quantities obtained within the framework of holographic models with theoretical and experimental values obtained for them in other models further increases interest in these issues.

The object and subject of the research. The object of research is the temperature dependence of the interaction of baryons with mesons at finite temperatures. The subject of the study is the coupling constant and form factors corresponding to interaction peaks of nucleons and Δ-baryons with ρ-meson, ω-meson, and $\boldsymbol{a_1}$-mesons.

The goals and objectives of the research.

Within the framework of the soft-wall model of the holographic QCD, in a dense nucleon medium at finite temperatures, it is to reveal the dependence of the interaction of nucleons with vector mesons on the temperature of the medium, and also the dependence of the interaction of the baryon with spin 3/2 with vector and axial vector mesons on the temperature of the medium. The task is also to analyze the temperature dependence of the axial vector form factor and the axial radius of the nucleon and to find out how the temperature of the medium affects the interaction of hadrons with each other. In order to realize these goals, the following issues were studied:

1. Within the framework of the soft-wall model of AdS/QCD, in accordance with the expressions obtained for mesons and baryons at finite temperature, to obtain obvious expressions of profile functions for vector meson and nucleon fields;

2. To determine the Lagrangian characterizing the ρ-meson-nucleon and ω-meson-nucleon interactions within the framework of the soft-wall model of the holographic QCD at finite temperature and to study their temperature dependence. To compare the results obtained in

the soft-wall model at finite temperature with values obtained from other theoretical models and experiments;

3. Within the framework of the soft-wall model of the holographic QCD, the expression of the Lagrangian describing the interaction of ρ-meson, ω-meson and -meson with Δ-baryons and nucleon-Δ-baryon-transition interaction of ρ, ω and $\boldsymbol{a_1}$ mesons is determined for the finite temperature case. Solving the Rarita-Schwinger equation for Δ-baryons at finite temperature. Obtain expressions of interaction constants based on corresponding Lagrangian, analyze temperature dependences of coupling constants and compare with values and results obtained from other theoretical models and experiment;

4. To study the temperature dependence of the axial vector form factor of nucleons, the axial vector transition form factor and the radii corresponding to these form factors within the framework of the soft-wall model of the holographic QCD at finite temperature. For this purpose, to calculate the expression of the propagator of the axial vector meson and to find the expressions of the axial vector meson and to find the expressions of the axial vector form factor of nucleons, the axial vector transition form factors and their corresponding radii for the case with finite temperature

Research methods. The method of differential equations, methods of computing theory, modern programming and computing technologies, applied programs were used in the work.

Defense of the main scientific points:

1. The numerical value of the ρ-meson-nucleon, ω-meson-nucleon coupling constant, studied in the thermal dilaton soft-wall model of the holographic QCD, depends very weakly on the quark field number N_f and the pion decay constant F.

2. ρ-meson-Δ-baryon, ω-meson-Δ-baryon and a_1-meson-Δ-baryon, ρ-meson-nucleon-Δ-baryon, ω-meson-nucleon-Δ-baryon transition interaction constants, the axial vector form factor of nucleons and the axial radius of nucleons decrease sharply with increasing temperature and become zero around the confinement-deconfinement phase transition temperature.

3. The dependence Q^2 of the axial vector form factor studied in

the soft-wall model of the holographic QCD at a finite temperature is close to the results obtained from the hard-wall model of the theory of the same name and from the experiment.

4. In the process of β transformation, the probability of the transformation process decreases with the increase of the temperature of the nucleon medium.

Theoretical and practical significance of research.

1. For the first time in the dissertation, expressions dependent on temperature have been derived for the coupling constants of ρ, ω meson-nucleon interactions based on the AdS/QCD soft-wall model, and the temperature dependence of these constants has been investigated. It has been determined that as the temperature increases, the values of the coupling constants decrease, approaching zero near the confinement-deconfinement phase transition temperature. Additionally, based on the comparison of the coupling constants for ρ and ω mesons, it has been revealed that isospin symmetry is not broken at finite temperatures.

2. The temperature dependence of the coupling constants for ρ, ω, and a_1 meson-Δ baryon and ρ, ω meson-nucleon-Δ baryon transition interactions has been theoretically investigated for the first time within the framework of the temperature-introduced soft-wall model. It has been observed that as the value of the background scalar field increases, the values of these constants decrease, approaching zero near the confinement-deconfinement phase transition temperature.

3. In the context of the soft-wall model at finite temperatures, the expression for the propagator of the axial-vector field has been obtained. By utilizing the Lagrangian expression characterizing the coupling between the axial-vector and fermion fields within the AdS space with an embedded black hole, the temperature dependence of the nucleon's axial-vector form factor, axial-vector radius, and axial-vector transition radius have been investigated. It has been found that as the temperature increases, the values of the nucleon's axial-vector form factor and radius decrease, approaching zero around the confinement-deconfinement phase transition temperature.

4. Additionally, it has been determined that the likelihood of beta decay decreases with increasing temperature

Approval of research results. The main results of the dissertation work are as follows: On the School of Theoretical Physics and International Conference (METU, Turkey, Ankara 2020), at the "Modern Trends in Physics" VII International Conference (BSU, Baku, 2021), at the Republic Scientific Conference for PhD students and Young Researchers (SDU, Sumqayit, 2021), in the school of publication of the regional doctoral program on particle physics of theoretical and experimental physics (Tbilisi, Georgia, 2021), at the "World Congress on Quantum Physics" International Conference (Amsterdam, 2022), at the "Holography and its Applications" I International Conference (Damghan University, Iran, 2022), in the internship program for young scientists (Dubna, Russia, 2022), at the International Conference and school of publication "Recent Achievements in Fundamental Physics" (Tbilisi, Georgia, 2022), at the "Holography and its Applications" II International Conference (Damghan University, Iran, 2022), in the publication "Frontiers in Hhadron Physics" (Galileo Galilei Institute, Florence, Italy, 2023), at the International Scientific Conference dedicated to the 100th anniversary of the birth of the National Leader of Azerbaijan Heydar Aliyev on the topic "Problems of Modern Natural and Economic Sciences" (Ganja State University, Ganja, 2023), at the "Modern Trends in Physics" VIII International Conference (BDU, Baku, 2023), presented at the scientific seminars of Baku State University and the Physics Faculty (Baku, 2020-2023).

The organization where the dissertation work was carried out is the "Nuclear and High Energy Physics" laboratory of the Physics Institute of the Ministry of Science and Education.

The dissertation consists of separate sections with their respective volumes indicated, and the total volume of the dissertation is also provided. The dissertation work consists of an introduction, four chapters, main results, and a bibliography of 110 references, along with 46 figures. Dissertation volume (excluding gaps in the text and pictures, tables, graphs, appendices and bibliography) – 204,000 (including Introduction – 14,000, Chapter I – 62,000, Chapter II – 64,000, Chapter III – 34,000, Chapter IV – 28,000, conclusion – 2000) is a sign.

The main content of the dissertation includes the following:

The main content of the dissertation. In the introduction, information is given about the relevance of the subject of the dissertation, its main purpose, scientific innovations, scientific and practical importance, defended provisions, approval of the work, and research methods.

Chapter I is of an overview nature, and a broad interpretation of the principle of AdS/CFT duality is given without taking into account the temperature. Information about the 5-dimensional Anti-de-Sitter space, which is the first side of the AdS/CFT correspondence, the metric, coordinates, radius of curvature of this space, and the 4-dimensional conformal field theory standing on the second side of this principle, the conformal group for which this theory is satisfied here. At the end of the chapter, information is given on the correlation functions that relate these two different dimensional theories. The question of the creation of the soft-wall model of the holographic QCD has been clarified, the soft-wall model in the case of $T \to 0$ has been broadly interpreted, and the equation of motion for the vector and fermion fields has been obtained and solved in that model.

Chapter II provide a summary overview of the AdS/CFT correspondence principle considering the case with temperature. Information is given about the inclusion of a black hole inside the AdS space, and a dilaton field dependent on temperature is introduced into the soft wall model. The equations of motion for mesons and baryons in this model are solved. Special solutions for nucleon and vector mesons are obtained from these equations at finite temperature, and expressions for profile functions for mesons and nucleons are derived for both the ground and excited states.

In the subsequent paragraphs, expressions for Lagrangian densities describing the ρ and ω meson-nucleon interaction at the boundary of the AdS space in the temperature-included soft wall model of holographic QCD are written depending on temperature. Integral expressions are obtained based on consideration of these interaction Lagrangians. Temperature-dependent expressions are derived for the additions to the ρ and ω meson-nucleon coupling constants by applying the holographic correspondence principle. The temperature dependence of the numerical values of these constants for both ground and excited states is studied for various values of the model parameters

The AdS-Schwarschild metric is as follows:

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

he dilaton field expressed in terms of the coordinate r is given by

$$\varphi(r,T) = K_T^2 r^2 = (1+\rho_T)k^2 r^2. \quad (2)$$

The expression for ρ_T is as follows:

$$\rho_T = \left[1 - \frac{N_f^2-1}{N_f}\frac{T^2}{12F^2} - \frac{N_f^2-1}{2N_f^2}\left(\frac{T^2}{12F^2}\right)^2\right] \quad (3)$$

The vector meson profile function is characterized by the following expression at finite temperature[1]:

$$M_0(r,T) = \sqrt{2}K_T^2 r^{3/2} e^{-\varphi(r,T)/2} \quad (4)$$

The nucleon profile function at finite temperature is given by the following expression[2]:

$$F_{nJ}^{L,R}(r,T) = \sqrt{2}K_T^{m_{L,R}+1} r^{m_{L,R}+\frac{1}{2}} e^{\frac{-\varphi(r,T)}{2}} L_n^{m_{L,R}}(K_T^2 r^2) \quad (5)$$

To investigate the temperature dependence of the coupling constant between mesons and nucleons, one constructs the Lagrangian of the AdS/QCD model based on the gauge invariance.

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1 Gutsche T. Mesons in a soft-wall AdS-Schwarzschild approach at low temperature / T. Gutsche, V. E. Lyubovitskij, I. Schmidt [et al.] // Physical Review D, - College Park: - 2019. - 99, - p. 054030

2 Gutsche T. Baryons in a soft-wall AdS-Schwarzschild approach at low temperature / T. Gutsche, V. E. Lyubovitskij, I. Schmidt [et al.] // Physical Review D, - College Park: - 2019. - 99, - p. 114023.

By introducing a black hole within the AdS space, the coupling Lagrangian between vector, scalar, and spinor fields within the black hole-included AdS space can be expressed as a function of radial coordinates r and temperature T as follows:

$$\mathcal{L}_{q.t}(x,r,T) = \mathcal{L}^{(0)}_{\rho NN}(x,r,T) + \mathcal{L}^{(1)}_{\rho NN}(x,r,T) + \mathcal{L}^{(2)}_{\rho NN}(x,r,T). \quad (6)$$

As a result of selecting fields dependent on temperature in the minimal coupling Lagrangian between vector and spinor fields at finite temperature, the Lagrangian reduces to the following form:

$$\mathcal{L}^{(0)}_{\rho NN}(x,r,T) = \bar{N}_1(x,r,T) e^M_A \Gamma^A M_M(x,r,T) N_1(x,r,T) + \\ + \bar{N}_2(x,r,T) e^M_A \Gamma^A M_M(x,r,T)\, N_2(x,r,T). \quad (7)$$

Ignoring the action of temperature in the momentum space through the Fourier transformation, the temperature-dependent 5-dimensional spinors $N_1(x,r,T)$ and $N_2(x,r,T)$ are expressed in the following form:

$$N_1(x,r,T) = N_{1L}(x,r,T) + N_{1R}(x,r,T) = \\ \frac{1}{(2\pi)^4}\int d^4p'\, e^{-ipx}[F_{1L}(r,T)u_L(p) + +F_{1R}(r,T)u_R(p)], \\ N_2(x,r,T) = N_{2L}(x,r,T) + N_{2R}(x,r,T) = \\ \frac{1}{(2\pi)^4}\int d^4p'\, e^{-ipx}[F_{2L}(r,T)u_L(p) + +F_{2R}(r,T)u_R(p)]. \quad (8)$$

Similarly, the spinors $\bar{N}_1(x,r,T)$ and $\bar{N}_2(x,r,T)$ are expressed in the same manner, accounting for the action of temperature:

$$\bar{N}_1(x,r,T) = \bar{N}_{1L}(x,r,T) + \bar{N}_{1R}(x,r,T) = \\ \frac{1}{(2\pi)^4}\int d^4p'\, e^{ip'x}[F^*_{1L}(r,T)\bar{u}_L(p') + + F^*_{1R}(r,T)\bar{u}_R(p')], \\ \bar{N}_2(x,r,T) = \bar{N}_{2L}(x,r,T) + \bar{N}_{2R}(x,r,T) = \\ \frac{1}{(2\pi)^4}\int d^4p'\, e^{ip'x}[F^*_{2L}(r,T)\bar{u}_L(p') + +F^*_{2R}(r,T)\bar{u}_R(p')] \quad (9)$$

where $F_{1L}(r,T)$ and $F_{1R}(r,T)$ are finite temperature left and right profile functions for nucleons.

The expressions (9) is considered in the context of equation (7). Subsequently, using the relations of Dirac matrices, certain calculations are performed. After all these calculations, the expression of the 5-dimensional $S_{\rho NN}^{(0)nm}(T)$ action at finite temperature is reduced to the following form:

$$S_{\rho NN}^{(0)nm}(T) =$$
$$\int d^4p\, d^4p' \bar{u}\, \gamma^{\mu} u\, V_{\mu}(q) \int_0^{\infty} \frac{dr}{r^4}\, e^{-\varphi(r,T)}\, M_0(r,T) \left(F_{1L}^{(n)*}(r,T) F_{1L}^{(m)}(r,T) + \right.$$
$$\left. + F_{2L}^{(n)*}(r,T) F_{2L}^{(m)}(r,T)\right). \qquad (10)$$

According to the holographic principle of correspondence, the theoretical function on the boundary of the 5-dimensional AdS space is equal to the theoretical function inside this space. The correspondence of the theoretical functions between the two theories is expressed for the finite temperature state as follows:

$$Z_{QCD}(T) = e^{iS_{q.t}(T)} = Z_{AdS}(T). \qquad (11)$$

To determine the nucleon current at finite temperature, the variation of the meson field $M_{\mu}^{a}(q)$ from equation (11) is taken with respect to the vacuum value on the boundary as follows:

$$< J_{\mu}(T) >= -i \frac{\delta Z_{QCD}(T)}{\delta M_{\mu}^{a}(q)} |_{M_{\mu}^{a}=0}. \qquad (12)$$

Here, J_{μ} is the 5-dimensional vector current in the source, originating from the vector meson field M_{μ}^{a} and representing the vector current for nucleons at finite temperature. It is obtained from equation (12) as follows:

$$J_{\mu}(p',p,T) = g_{\rho NN}(T) \bar{u}(p') \gamma_{\mu} u(p). \qquad (13)$$

Here, p' is the momentum of the nucleon field at finite temperature before the interaction, and p is the subsequent momentum. There is an energy-momentum conservation law between the 4-dimensional q and p' momenta, denoted as $q = p' - p$.

In equation (13), the addition of the coupling constant $g_{\rho NN}^{(s.w)nm}(T)$ to the vector meson-nucleon current $g_{\rho NN}^{(0)nm}(r,T)$ is determined.

$$g_{\rho NN}^{(0)nm}(T) = \int_0^\infty \frac{dr}{r^4}\, e^{-\varphi(r,T)}\, M_0(r,T)\left(F_{1L}^{(n)*}(r,T)F_{1L}^{(m)}(r,T) + \right.$$
$$\left. +F_{2L}^{(n)*}(r,T)F_{2L}^{(m)}(r,T)\right). \qquad (14)$$

Here, $M_0(r,T)$ represents the vector meson field, while $F_{1L}^{(n)}(r,T)$ and $F_{1R}^{(m)}(r,T)$ denote the profile functions of nucleons at finite temperature. The indices n, m indicate the initial and final excited states of nucleons, respectively.

Given that nucleons possess magnetic moments, they can interact through these moments as well. In the 5-dimensional theory, such magnetic-type coupling Lagrangian terms have been established, and their contribution to the meson-nucleon coupling constant has been calculated within the framework of an additional hard-wall model. It is also considered that fermion fields within the 5-dimensional space interact magnetically with the vector field. The coupling of nucleons within the AdS space, described by Γ^{AB}, is related to the magnetic moment. The four-dimensional components of the Γ^{MN} tensor correspond to the fermions' magnetic moment. The Lagrangian describing this interaction remains invariant under Lorentz, gauge, and parity symmetries.

In the 5-dimensional theory, at finite temperature, the Lagrangian $\mathcal{L}_{FNN}^{(1)}(x,r,T)$ corresponding to this coupling is constructed as follows:

$$\mathcal{L}_{\rho NN}^{(1)}(x,r,T) = ik_1 e_A^M e_B^N(\bar{N}_1(x,r,T)\Gamma^{AB}(F_L)_{MN} N_1(x,r,T) - \bar{N}_2(x,r,T)\Gamma^{AB}(F_R)_{MN}N_2(x,r,T) - h.c.) = ik_1 e_A^M e_B^N(\bar{N}_1(x,r,T)\Gamma^{AB}F_{MN} N_1(x,r,T) - \bar{N}_2(x,r,T)\Gamma^{AB}F_{MN}N_2(x,r,T) - h.c.). \quad (15)$$

After considering equations (8) and (9) in the context of equation (15), the following expression is obtained for the action $S_{\rho NN}^{(1)nm}(T)$:

$$S_{\rho NN}^{(1)nm}(T) = -2\int d^4p\, d^4p'\bar{u}\gamma^\mu u\, V_\mu(q,T)\int_0^\infty \frac{dr}{r^3}\, e^{-\varphi(r,T)}\times$$
$$\times M_0'(r,T)[k_1\left(F_{1L}^{(n)*}(r,T)F_{1L}^{(m)}(r,T) - F_{2L}^{(n)*}(r,T)F_{2L}^{(m)}(r,T)\right) +$$
$$+k_2\, v(r,T)\left(F_{1L}^{(n)*}(r,T)F_{2L}^{(m)}(r,T) + F_{2L}^{(n)*}(r,T)F_{1L}^{(m)}(r,T)\right)] \quad (16)$$

where i is a complex number and $k1$ is a parameter. After applying the holographic correspondence principle to equation (16) in equation (11), the coupling constant $g_{\rho NN}^{(s.w)nm}(T)$ from the vector meson-nucleon current (13) the following integral expression is obtained:

$$g_{\rho NN}^{(1)nm}(T) = -2\int_0^\infty \frac{dr}{r^3}\, e^{-\varphi(r,T)}\, M_0'(r,T) *$$
$$* [k_1\left(F_{1L}^{(n)*}(r,T)F_{1L}^{(m)}(r,T) - F_{2L}^{(n)*}(r,T)F_{2L}^{(m)}(r,T)\right) +$$
$$+k_2\, v(r,T)\left(F_{1L}^{(n)*}(r,T)F_{2L}^{(m)}(r,T) + F_{2L}^{(n)*}(r,T)F_{1L}^{(m)}(r,T)\right)]. \quad (17)$$

In addition to the magnetic-type coupling between fermion and meson fields within the 5-dimensional AdS space at finite temperature, there is also a coupling with the scalar field skalyar $X(r,T)$. Considering the coupling of this field in the soft-wall model at finite temperature, the Lagrangian function is written as follows:

$$\mathcal{L}_{MNN}^{(2)}(x,r,T) = \frac{i}{2}k_2 e_A^M e_B^N (\bar{N}_1(x,r,T)X(r,T)\,\Gamma^{AB}(F_R)_{MN}N_2(x,r,T) + \bar{N}_2(x,r,T)X^+(r,T)\Gamma^{AB}(F_L)_{MN}N_1(x,r,T) - h.c) = \frac{i}{2}k_2 e_A^M e_B^N (\bar{N}_1(x,r,T)X\,(r,T)\Gamma^{AB}F_{MN}N_2(x,r,T) + +\bar{N}_2(x,r,T)X^+(r,T)\Gamma^{AB}F_{MN}N_1(x,r,T) - h.c). \quad (18)$$

The "lagrangian expression" in the AdS space expresses the interaction between fermions' magnetic and gauge fields, as well as the $X(r,T)$ field. The coupling of these three fields results in changes in the chirality of fermions. At finite temperature, the total magnetic interaction is equal to the sum of the first and second terms:

$$\mathcal{L}_{MNN}^{q.t}(x,r,T) = \mathcal{L}_{MNN}^{(1)}(x,r,T) + \mathcal{L}_{MNN}^{(2)}(x,r,T). \quad (19)$$

When considering the interaction integral in terms of $\mathcal{L}_{MNN}^{(2)}$, the expression for the action $S_{\rho NN}^{(2)nm}(T)$is obtained as follows:

$$S_{\rho NN}^{(2)nm}(T) = 4m_N \int d^4p\, d^4p' \bar{u}\,\gamma^\mu u\, V_\mu(q,T) \int_0^\infty \frac{dr}{r^3}\, e^{-\varphi(r,T)}\, M_0(r,T) [k_1 \left(F_{1L}^{(n)*}(r,T)F_{1R}^{(m)}(r,T) - -F_{2L}^{(n)*}(r,T)F_{2R}^{(m)}(r,T)\right) + +k_2\, v(r,T)\left(F_{1L}^{(n)*}(r,T)F_{2R}^{(m)}(r,T) + +F_{2L}^{(n)*}(r,T)F_{1R}^{(m)}(r,T)\right)]. \quad (20)$$

The holographic correspondence principle (Equation 20) is applied to equation (20), yielding the expression for the current $J_\mu(p',p,T) = f_\rho^{nm}(T)\bar{u}(p')\gamma_\mu u(p)$. The temperature-dependent expression for the coupling constant $f_\rho^{nm}(T)$ is found as follows:

$$f_\rho^{nm}(T) = 4m_N \int_0^\infty \frac{dr}{r^3}\, e^{-\varphi(r,T)}\, M_0(r,T) *$$
$$* [k_1 \left(F_{1L}^{(n)*}(r,T)F_{1R}^{(m)}(r,T) - F_{2L}^{(n)*}(r,T)F_{2R}^{(m)}(r,T)\right) +$$
$$+k_2\, v(r,T) \left(F_{1L}^{(n)*}(r,T)F_{2R}^{(m)}(r,T) + F_{2L}^{(n)*}(r,T)F_{1R}^{(m)}(r,T)\right)]. \quad (21)$$

The final coupling coefficient is equal to the sum of two couplings, $g_{\rho NN}^{y.d.}(T) = g_{\rho NN}^{(0)nm}(T) + g_{\rho NN}^{(1)nm}(T)$. Afterwards, the meson $M_0(r,T)$, nucleon $F_{L,R}^{(n,m)}(r,T)$, and scalar field $v(r,T)$ profile functions are considered in the expressions of coupling coefficients, and numerical integration is performed with respect to the radial coordinate r.

After performing the integration, the expressions for the additions of coupling coefficients depend solely on temperature. To determine the temperature dependence of these expressions, the "Mathematica" program is applied, thereby determining how the numerical value of the ρ meson-nucleon coupling coefficient changes with temperature.

Expressions for the coupling coefficients $g_{\rho NN}^{(0)nm}(T)$, $g_{\rho NN}^{(1)nm}(T)$, and $f_\rho^{nm}(T)$ were obtained for the purpose of calculating numerical integrals using the "Mathematica" program within the soft-wall model. Subsequently, the temperature dependence of each of these coupling coefficients was investigated considering different quark flavor numbers $N_f = 2, 3, 4{,}5$ and corresponding pion decay constant values $F = 0.87 GeV,\ 0.1\ GeV,\ 0.13\ GeV, 0.14\ GeV$.

During these calculations, the numerical values of the free parameters k, k_1, k_2, m_q and Σ in the soft-wall model were determined based on the numerical values of the $g_{\rho NN}$and $g_{\pi NN}$ coupling constants in the hard-wall model, as reported in reference. Specifically, k=0.383 GeV, $k_1 = -0.78$, $k_2 = 0.5$, $\Sigma = (0.363)^3\ GeV^3$ and $m_q = 0.000145\ GeV$ These parameter values were fixed for the calculations in the soft-wall model.

In order to determine the contributions of various Lagrangian terms to the coupling constant and their dependence on temperature, the temperature dependence of these terms was investigated separately[3]. The temperature dependence of the coupling constant and its additions were compared in Figure 1 and Figure 2, considering different quark flavor parameters $N_f = 2, 3, 4, 5$ and corresponding pion decay constant values $F = 0.087\,GeV, 0.1\,GeV, 0.13\,GeV, 0.14\,GeV$. In the following figures, the blue curve represents the temperature dependence of $g_{\rho NN}^{(0)nm}(T)$, the orange curve represents $g_{\rho NN}^{(1)nm}(T)$, the green curve represents $g_{\rho NN}^{y.d.}(T)$, and the red curve represents the temperature dependence of $f_{\rho}^{nm}(T)$ additions.

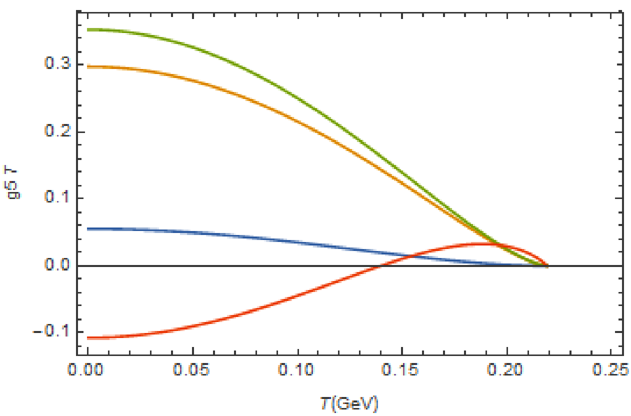

Figure 1. Temperature dependence of the $g_{\rho NN}^{(0)nm}(T)$, $g_{\rho NN}^{(1)nm}(T)$, $g_{\rho NN}^{s.w.}(T)$ and $f_{\rho}^{nm}(T)$ at $N_f = 2$ in the ground state of nucleons

[3] Mamedov, Sh. Temperature dependence of ρ meson-nucleon coupling constant from the AdS/QCD soft-wall model / Sh. Mamedov, N. Nasibova // Physical Review D, - College Park: - 2021. - 104, - p. 036010.

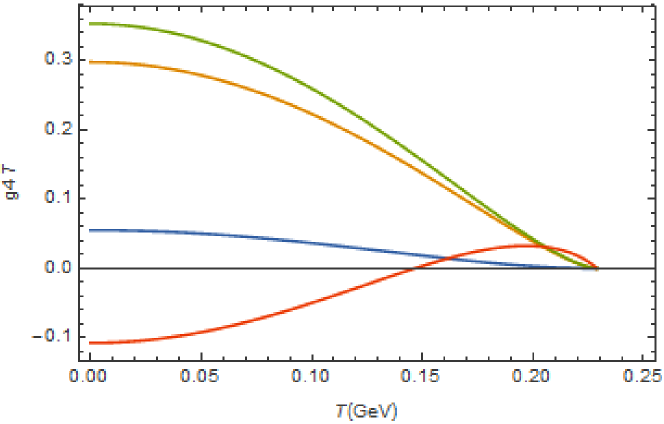

Figure 2. Temperature dependence of the $g_{\rho NN}^{(0)nm}(T)$, $g_{\rho NN}^{(1)nm}(T)$, $g_{\rho NN}^{s.w.}(T)$ and $f_{\rho}^{nm}(T)$ at $N_f = 3$ in the ground state of nucleons

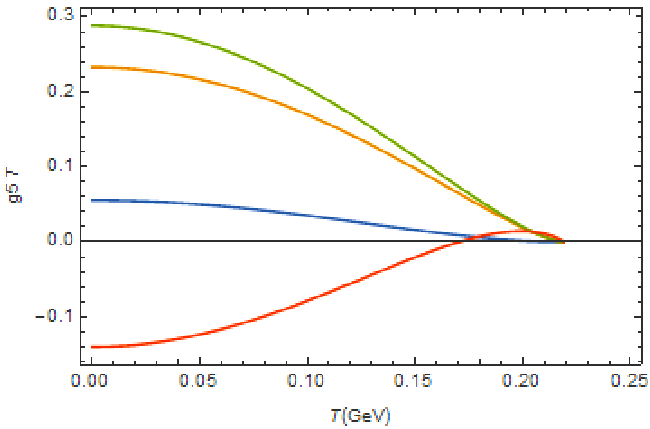

Figure 3. Temperature dependence of the $g_{\rho NN}^{(0)nm}(T)$, $g_{\rho NN}^{(1)nm}(T)$, $g_{\rho NN}^{s.w.}(T)$ and $f_{\rho}^{nm}(T)$ at $N_f = 2$ in the excited state of nucleons

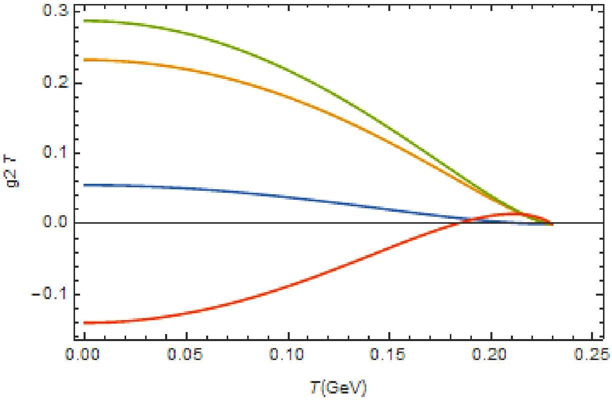

Figure 4. Temperature dependence of the $g_{\rho NN}^{(0)nm}(T)$, $g_{\rho NN}^{(1)nm}(T)$, $g_{\rho NN}^{s.w.}(T)$ and $f_{\rho}^{nm}(T)$ at $N_f = 3$ in the excited state of nucleons

The blue curve in the above figures represents the temperature dependence of the ρ meson-nucleon coupling constant $g_{\rho NN}^{(0)nm}(T)$, the orange curve represents $g_{\rho NN}^{(1)nm}(T)$, the green curve represents $g_{\rho NN}^{s.w.}(T)$ and the red curve represents $f_{\rho}^{nm}(T)$.

The equality of the quantum numbers of the ρ and ω mesons simplifies the study of the ω meson-nucleon coupling constant at finite temperature. A proportionality between the ω and ρ meson coupling constants is established as $N_c g_\rho(T) = g_\omega(T)$ where $(N_c = 3)$.

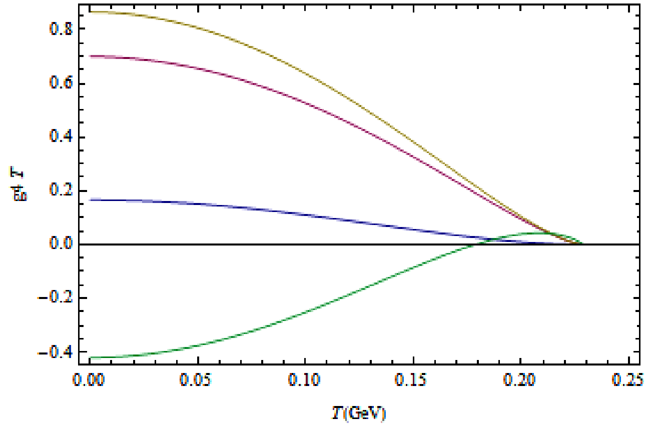

Figure 5. Temperature dependence of the $g_{\omega NN}^{(0)nm}(T)$, $g_{\omega NN}^{(1)nm}(T)$, $g_{\omega NN}^{s.w.}(T)$ and $f_{\omega}^{nm}(T)$ for $N_f = 2$ in ground state of nucleons

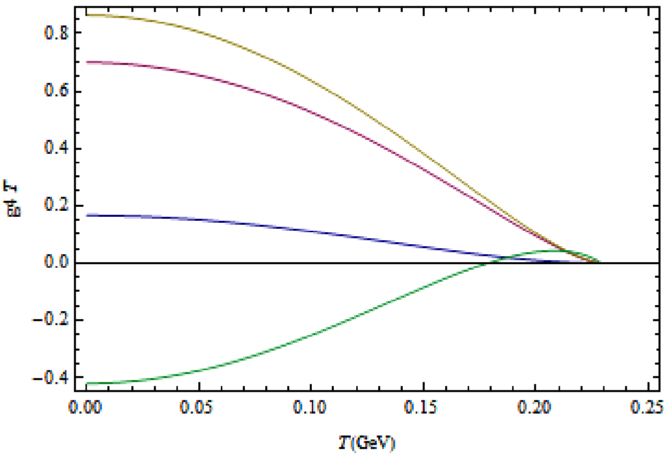

Figure 6. Temperature dependence of the $g_{\omega NN}^{(0)nm}(T)$, $g_{\omega NN}^{(1)nm}(T)$, $g_{\omega NN}^{s.w.}(T)$ and $f_{\omega}^{nm}(T)$ for $N_f = 3$ in ground state of nucleons

The yellow curve represents the temperature dependence of the $g_{\omega NN}^{(0)nm}(T)$, coupling constant, the purple curve represents $g_{\omega NN}^{(1)nm}(T)$, the blue curve represents $g_{\omega NN}^{s.w.}(T)$ and the green curve corresponds to $f_{\omega}^{nm}(T)$ coupling constant addition.

In Chapter III, the theoretical framework for the finite temperature Rarita-Schwinger action within the soft-wall model in the AdS space has been formulated and solved. The Lagrangian expressions describing the vector and axial-vector meson-baryon interaction at finite temperature have been derived. Based on these expressions, the expressions characterizing the interaction between fields in the AdS space have been obtained. By applying the holographic correspondence principle, the holographic expressions for the ρ, ω meson-Δ baryon, a_1 meson$-\Delta$ baryon, and ρ, ω meson-nucleon-Δ baryon transition coupling constants in the soft-wall model of holographic QCD (holographic QCD) have been obtained and their temperature dependence has been investigated. Subsequently, by varying the parameters within the model, the temperature dependence graphs of the minimal coupling constants of these hhadrons have been drawn, and the influence of temperature on the coupling constants has been studied. According to the AdS/CFT correspondence, the internal fields imposed on the determined nucleon and Δ baryon operators at the boundary of the AdS space differ from each other. Specifically, while Dirac fields correspond to nucleons with spin 1/2 within the AdS space, Rarita-Schwinger fields Ψ_M are imposed on operators corresponding to Δ baryons with spin 3/2. It's worth noting that in theoretical physics, the Rarita-Schwinger equation is the relativistic field equation for fermions with spin 3/2. This equation was first introduced in 1941 by William Rarita and Julian Schwinger, and it is analogous to the Dirac equation for fermions with spin 1/2.

To find the Δ baryon profile function at finite temperature in the soft-wall model of holographic QCD, the action dependent on 4-dimensional influence is written in terms of 5-dimensional temperature as follows:

$$S(T) = \int d^5x \sqrt{g} e^{-\varphi(r,T)} (i\bar{\Psi}_A \Gamma^{ABC} D_B \Psi_C - m_1 \bar{\Psi}_A \Psi^A - \\ - m_2 \bar{\Psi}_A \Gamma^{AB} \Psi_B). \quad (22)$$

After considering variations in the influence and performing certain calculations, the following equation for the motion equation is obtained:

$$i\Gamma^A(D_A\Psi_B(x,r,T) - D_B\Psi_A(x,r,T)) - m_-\Psi_B(x,r,T) + \\ + \frac{m_+}{3}\Gamma_B\Gamma^A\Psi_A(x,r,T) = 0. \tag{23}$$

Here $m_\mp = m_1 \mp m_2$. In the 4-dimensional space, the Rarita–Schwinger field in the AdS space preserves both cases with spin 3/2 and 1/2 corresponding to the masses m_1 and m_2 respectively. However, since we are only interested in baryons with spin 3/2, it is necessary to eliminate the cases with spin 1/2. To achieve this, a condition is imposed in the 5-dimensional space consistent with the 4-dimensional condition $\gamma^\mu\Psi_\mu = 0$. At finite temperature in the AdS space, the Lorentz condition:

$$e_A^M\Gamma^A\Psi_M(x,r,T) = 0 \tag{24}$$

is imposed on the Rarita–Schwinger field. The Lorentz condition eliminates only one of the components with spin 1/2. Considering Lorentz condition in equation (24), for a free particle, we obtain the expression $\partial^M\Psi_M(x,r,T) = 0$. The second spin 1/2 component, $\Psi_r(x,r,T)$, arises during the transition from the 5-dimensional space to the 4-dimensional space. The condition

$$\Psi_r(x,r,T) = 0 \tag{25}$$

is chosen to remove the additional cases. After considering the Lorentz condition (24) and performing certain calculations, the resulting action functional for the Dirac matrices, covariant derivative, dilaton field, and metric is expressed in the following form:

$$(ir\Gamma^A\partial_A + 2i\Gamma^5 - m_-)\Psi_\mu = 0, \tag{26}$$

To describe baryons (resonances) with spin 3/2 in the soft-wall model of AdS/QCD at finite temperature, we introduce left-handed and right-handed fields $\Psi_{A(L)} = \frac{1}{2}(1-\gamma^5)f_L$ and $\Psi_{A(R)} = \frac{1}{2}(1+\gamma^5)f_R$ as components of the Rarita-Schwinger tensor field satisfying equation (26). Consequently, after considering the expressions for left and right Rarita-Schwinger fields and spinors, as well as Dirac matrices, from equation (27) and performing certain calculations, the following system of differential equations is obtained[4]:

$$\left[\partial_r^2 - \frac{2\left(m_- + K^2(T)r^2\right)}{r}\partial_r + \frac{2\left(m_- - K^2(T)r^2\right)}{r^2} + p^2\right] f_R = 0,$$
$$\left[\partial_r^2 - \frac{2\left(m_- + K^2(T)r^2\right)}{r}\partial_r + p^2\right] f_L = 0. \qquad (27)$$

The functions representing the profiles are obtained by solving the even parity eigenvalue equation for Δ baryons with spin 3/2 at finite temperature. The profile functions of Δ baryons are given as follows:

$$f_{nJ}^L(r,T) = \sqrt{\frac{2\Gamma(n+1)}{\Gamma(n+3)}} K_T^3 r^{\frac{5}{2}} e^{-\frac{K_T^2 r^2}{2}} L_n^2(K_T^2 r^2),$$

$$f_{nJ}^R(r,T) = \sqrt{\frac{2\Gamma(n+1)}{\Gamma(n+2)}} K_T^2 r^{\frac{3}{2}} e^{-\frac{K_T^2 r^2}{2}} L_n^1(K_T^2 r^2). \qquad (28)$$

These solutions satisfy the normalization condition.

At finite temperature, the interaction Lagrangian $\mathcal{L}_{\rho\Delta\Delta}^{(0)}(x,r,T)$ expressing the interaction between the internal vector meson field and the Δ baryon current is written as follows.

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[4] Nasibova, N. Meson-delta and meson-nucleon-delta transition coupling constants in the soft-wall model of holographic QCD at finite temperature / Letters in High Energy Physics, 2022. - 326, - p. 31526.

$$\mathcal{L}^{(0)}_{\rho\Delta\Delta}(x,r,T) = \bar{\Psi}^{\nu}_{1}(x,r,T)\Gamma^{\mu}M_{\mu}(x,r,T)\Psi_{1\nu}(x,r,T) + \\ +\bar{\Psi}^{\nu}_{2}(x,r,T)\Gamma^{\mu}M_{\mu}(x,r,T)\Psi_{2\nu}(x,r,T). \qquad (29)$$

At finite temperature, the interaction Lagrangian expressing the interaction between the Δ baryon field inside the AdS space with the ρ meson field, as well as the $X(x,r,T)$scalar field, is written as follows:

$$\mathcal{L}^{(1)}_{\rho\Delta\Delta}(x,r,T) = \\ = ik_3(\bar{\Psi}^{M}_{1}\Gamma^{NP}(F_L)_{NP}\Psi_{1M} - \bar{\Psi}^{M}_{2}\Gamma^{NP}(F_R)_{NP}\Psi_{2M}) + \\ +\frac{i}{2}k_4(\bar{\Psi}^{M}_{1}(x,r,T)X^3(x,r,T)\Gamma^{NP}(F_R)_{NP}\Psi_{2M}(x,r,T) + \\ +\bar{\Psi}^{M}_{2}(x,r,T)\,(X^{+})^3(x,r,T)\Gamma^{NP}(F_L)_{NP}\Psi_{2M}(x,r,T)\,). \qquad (30)$$

$\mathcal{L}^{(0)}_{\rho\Delta\Delta}(x,r,T)$ və $\mathcal{L}^{(1)}_{\rho\Delta\Delta}(x,r,T)$ laqranjianlarından uyğun olaraq. $g^{(0)nm}_{\rho\Delta\Delta}(T)$ üçünAccording to the corresponding Lagrangians $\mathcal{L}^{(0)}_{\rho\Delta\Delta}$ and $\mathcal{L}^{(1)}_{\rho\Delta\Delta}(x,r,T)$, the coupling constant $g^{(0)nm}_{\rho\Delta\Delta}(T)$ is determined as follows:

$$g^{(0)nm}_{\rho\Delta\Delta}(T) = \\ \int_0^{\infty}\frac{dr}{r^2}\,e^{-\Phi(r,T)}\,M_0(r,T)\left(f^{(n)*}_{1L}(r,T)f^{(m)}_{1L}(r,T) + \right. \\ \left. + f^{(n)*}_{2L}(r,T)f^{(m)}_{2L}(r,T)\right). \qquad (31)$$

The expression for the $g^{(1)nm}_{\rho\Delta\Delta}(r,T)$ is obtained as folloüing form:

$$g^{(1)nm}_{\rho\Delta\Delta}(T) = \\ -2\int_0^{\infty}\frac{dr}{r}\,e^{-\Phi(r,T)}\,M_0'(r,T)[k_3\left(f^{(n)*}_{1L}(r,T)f^{(m)}_{1L}(r,T) - \right. \\ \left. -f^{(n)*}_{2L}(r,T)f^{(m)}_{2L}(r,T)\right)] + k_4[\left(v(r,T)\right)^3\left(f^{(n)*}_{1L}(r,T)f^{(m)}_{2L}(r,T) + \right. \\ \left. +f^{(n)*}_{2L}(r,T)f^{(m)}_{1L}(r,T)\right)]. \qquad (32)$$

The explicit expression for the interaction Lagrangian $\mathcal{L}^{(0)}_{\rho N\Delta}(x,r,T)$ is as follows:

$$\mathcal{L}^{(0)}_{\rho N\Delta} = \alpha_1(\overline{\Psi}^M_1\Gamma^N(F_L)_{MN}N_1 - \overline{\Psi}^M_2\Gamma^N(F_R)_{MN}N_2). \quad (33)$$

In a similar manner, the temperature-dependent expression for the coupling constant $g^{(0)}_{\rho N\Delta}(T)$is found as follows:

$$g^{nm}_{\rho N\Delta}(T) =$$
$$\int_0^\infty dr\, e^{-\varphi(r,T)} [\, \frac{1}{r^2} M_0'(r,T)\left(k_1(F^{(n)*}_{1L}(r,T)f^{(m)}_{1R}(r,T) -\right.$$
$$\left. - F^{(n)*}_{2L}(r,T)f^{(m)}_{2R}(r,T)\right). \quad (34)$$

Based on the interaction Lagrangian $L^{(0)}(x,z)$ for the interaction between the axial-vector field and the Ψ_M Rarita-Schwinger field, the temperature-dependent Lagrangian $L^{(0)}(x,r,T)$ is expressed as follows:

$$\mathcal{L}^{(0)}_{a_1\Delta\Delta}(x,r,T) = \frac{1}{2}(\overline{\Psi}^M_1(x,r,T)e^M_A\Gamma^M A_M(r,T)\Psi_{1M}(x,r,T) -$$
$$\overline{-\Psi}^M_2(x,r,T)e^M_A\Gamma^M A_M(r,T)\Psi_{2M}(x,r,T)). \quad (35)$$

The Lagrangian describing the interaction between the $a1$ meson and the Δ baryons in the magnetic type $\mathcal{L}^{(1)}_{a_1\Delta\Delta}(x,r,T)$ is written as follows:

$$\mathcal{L}^{(1)}_{a_1\Delta\Delta}(x,r,T) = \frac{i}{2}k_1 e^M_A e^N_B\left(\overline{\Psi}^M_1(x,r,T)\Gamma^{MN}F_{MN}\Psi_{1M}(x,r,T) +\right.$$
$$\left. + \overline{\Psi}^M_2(x,r,T)\Gamma^{MN}F_{MN}\Psi_{2M}(x,r,T)\right). \quad (36)$$

From the expressions of the respective Lagrangians, the coupling constant $g^{(0)}_{a_1\Delta\Delta}(T)$ and $g^{(1)}_{a_1\Delta\Delta}(T)$ are determined as follows:

$$g^{(0)}_{a_1\Delta\Delta}(T) = \frac{1}{2}\int_0^\infty e^{-\varphi(r,T)}\frac{dr}{r^2}A_n(r,T)\,[|f_{1R}(r,T)|^2 - |f_{1L}(r,T)|^2]. \quad (37)$$

$$g^{(1)}_{a_1\Delta\Delta}(T) = \frac{k_1}{2}\int_0^\infty e^{-\varphi(r,T)}\frac{dr}{r^3}\left(\partial_r A_n(r,T)\right)[|f_{1R}(r,T)|^2 + +|f_{1L}(r,T)|^2]. \quad (38)$$

After finding the integral expressions of $g^{(0)nm}_{\rho\Delta\Delta}(T)$, meson-nucleon-Δ-baryon $g^{(0)nm}_{\rho N\Delta}(T)$, and ω meson-Δ baryon $g^{(0)nm}_{\omega\Delta\Delta}(T)\omega$ meson-nucleon-Δ-baryon $g^{(0)nm}_{\omega N\Delta}(T)$ couplings, the temperature dependencies of the coupling constants have been plotted.

In the figures, the corresponding sky-colored curve corresponds to $F = 0.087\,GeV$, the yellow curve to $F = 0.1\,GeV$ the green curve to $F = 0.13\,GeV$ and the purple curve to $F = 0.14\,GeV$. The results are taken for the Δ baryon in the ground state.

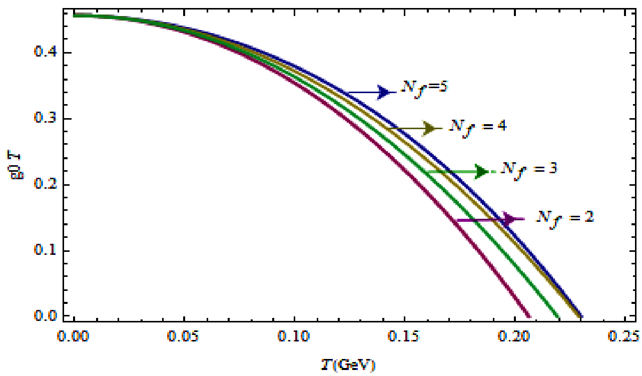

Figure 7. Temperature dependence of the coupling constant $g^0_{\rho\Delta\Delta}(T)$ at different values of the quark flavour number N_f

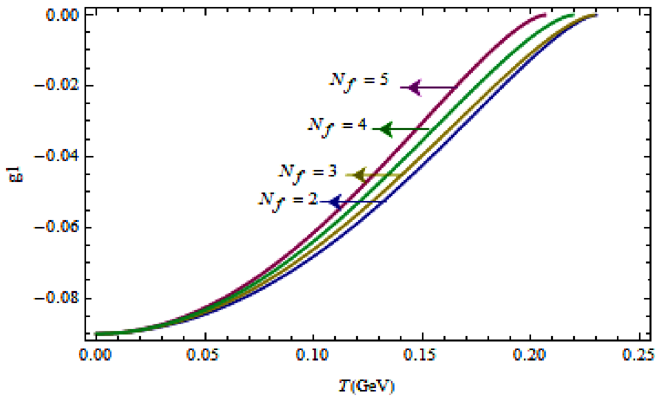

Figure 8. Temperature dependence of the coupling constant $g^0_{\rho N\Delta}(T)$at different values of the quark flavour number N_f

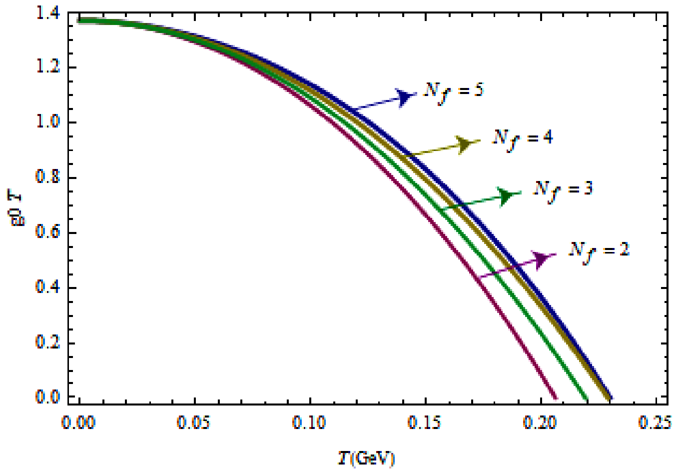

Figure 9. Temperature dependence of the coupling constant $g^0_{\omega\Delta\Delta}(T)$ at different values of the quark flavour number N_f

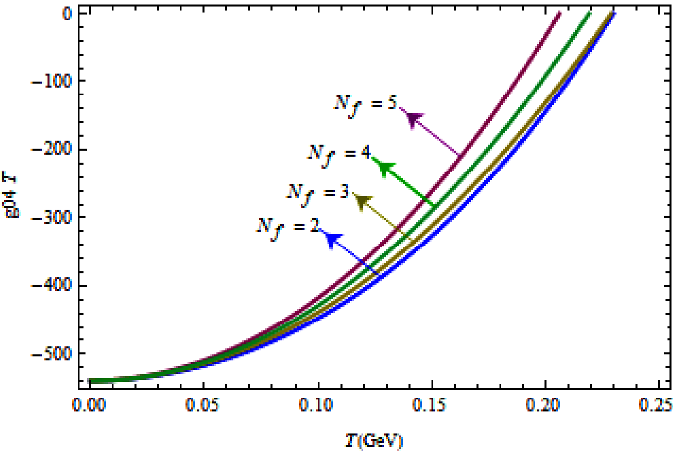

Figure 10. Temperature dependence of the coupling constant $g^{0}_{\omega N\Delta}(T)$ at different values of the quark flavour number N_f

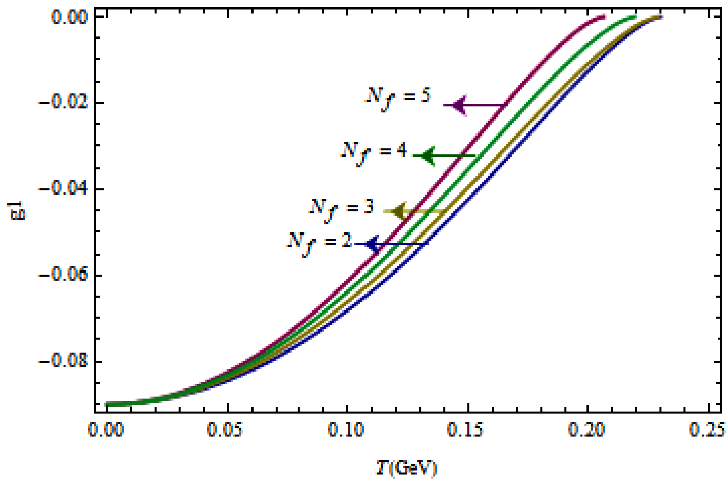

Figure 11. Temperature dependence of the coupling constant $g^{(0)nm}_{a_1\Delta\Delta}(T)$ at different values of the quark flavour number N_f

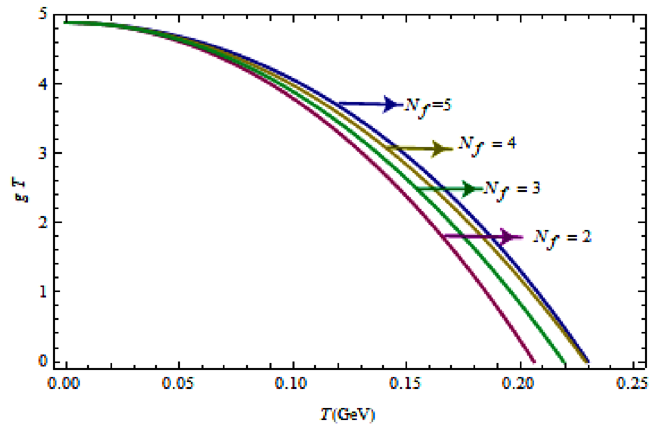

Figure 12. Temperature dependence of the coupling constant $g_{a_1\Delta\Delta}^{(1)nm}(r,T)$ at different values of the quark flavour number N_f

In Chapter IV, the expression for the axial-vector propagator of nucleons at finite temperature is derived, based on the Lagrangian constraints describing the interaction between the axial-vector field and the nucleon field. Using the expressions obtained for the AdS space fields, the temperature-dependent expressions for the axial-vector and axial-vector transition form factors of nucleons, as well as the radius, have been investigated for various values of model parameters.

At finite temperature, the axial-vector field $A_N(x,r,T)$ coincides with the scalar field $V_N(x,r,T)$. The expression for the axial-vector field at finite temperature is written as follows, according to the interaction written for the vector field at finite temperature:

$$S = \frac{(-)^J}{2}\int d^4\, xdre^{-\varphi_T(r)}\partial_M A_N(x,r,T)\partial^M A^N(x,r,T). \quad (39)$$

The Fourier transform of the axial-vector field $A^N(x,r,T)$ from internal to momentum space, denoted by $A(-q^2,r,T)$ is expressed as follows:

$$A_N(x,r,T) = \int \frac{d^4q}{(2\pi)^4} e^{-iqx} A_N(q) A_N(-q^2,r,T). \quad (40)$$

Then, by replacing $-q^2 = Q^2$ with Q^2 we transition to the domain of Q^2. By taking the variation with respect to $A_N(q)$ from the interaction expression, the following expression for the kinetic term is obtained[5]:

$$\partial_r\left(-\frac{e^{-\varphi_T(r)}}{dr}\partial_r A(Q,r,T)\right) - Q^2\frac{e^{-\varphi_T(r)}}{dr}A(Q,r,T) = 0. \quad (41)$$

When the effect of temperature is not considered, equation (41) differs from the action for the vector field by replacing z with r and k with $K(T)$. At finite temperature, the obtained action for the vector field coincides with it. Equation (41) is known as the internal-to-boundary propagator for the axial-vector field, and it is expressed as follows:

$$A(Q,r,T) = \left(\Gamma(1+a_T)\right)U(a_T,0,K^2(T)r^2) * \\ * \int_0^1 \frac{\mathrm{dx}}{(1-x)^2} x^{a_T} e^{-K^2(T)r^2\frac{\mathrm{x}}{1-x}} \quad (42)$$

Here $a_T = \frac{Q^2}{4K^2(T)}$. $\Gamma(1+a_T)$ is the gamma function, and, *U(x, y, z)* is the Tricomi function.

The interaction Lagrangian terms that contribute to the axial-vector form factor at finite temperature are expressed in the following form:

$$L^{(0)}(x,r,T) = \frac{1}{2}(\bar{\Psi}_1(x,r,T)\Gamma^M A_M(x,r,T)\Psi_1(x,r,T) - \\ \bar{\Psi}_2(x,r,T)\Gamma^M A_M(x,r,T)\Psi_2(x,r,T)). \quad (43)$$

[5] Mamedov, Sh. Axial-vector form factor of nucleons at finite temperature from the AdS/QCD soft-wall model / Sh. Mamedov, N. Nasibova // International Journal Modern Physics A, - Singapore: - 2023. - 38, №24, - p. 2350131.

The interaction Lagrangian term contributing to the axial-vector form factor at finite temperature can be expressed in the form of a magnetic-type interaction as follows:

$$L^{(1)}(x,r,T) = \frac{i}{2}k_1\{\bar{\Psi}_1(x,r,T)\Gamma^{MN}F_{MN}\Psi_1(x,r,T) + \\ + \bar{\Psi}_2(x,r,T)\Gamma^{MN}F_{MN}\Psi_2(x,r,T)\}. \quad (44)$$

The interaction Lagrangian term between the spinor, scalar, and axial-vector fields is written as follows:

$$L^{(2)}(x,r,T) = \frac{g_Y}{2}\{\bar{\Psi}_1(x,r,T)\Gamma^{M}A_M\Psi_1(x,r,T) + \\ +\bar{\Psi}_2(x,r,T)X^*(x,r,T)\Gamma^{M}A_M(x,r,T)\Psi_1(x,r,T)\}. \quad (45)$$

The interaction Lagrangian term is generally expressed as follows:

$$L(x,r,T) = L^{(0)}(x,r,T) + L^{(1)}(x,r,T) + L^{(2)}(x,r,T) \quad (46)$$

The Lagrangian constraints expressed by equations (46) are written in terms of the corresponding effective actions, taking into account the relation between the profile functions, where $F_{1L}^{(n)}(r,T) = -F_{2R}^{(m)}(r,T)$ and $F_{1R}^{(n)}(r,T) = F_{2L}^{(m)}(r,T)$[6].

Applying the holographic correspondence principle to the final expression, the following expressions for axial-vector form factor at finite temperature are obtained:

$$G_A^{(0)}(Q^2,T) = \frac{1}{2}\int_0^\infty e^{-\varphi(r,T)}drA(Q,r,T)\,[|F_{1R}(r,T)|^2 - \\ -|F_{1L}(r,T)|^2], \quad (47)$$

[6] Gutsche T. Electromagnetic properties of the nucleon and the Roper resonance in soft-wall AdS/QCD at finite temperature / T. Gutsche, V. E. Lyubovitskij, I. Schmidt // Nuclear Physics B, - London: - 2020. - 952, - p. 114934.

$$G_A^{(1)}(Q^2,T) = \frac{k_1}{2}\int_0^{\infty} e^{-\varphi(r,T)} dr\, r\left(\partial_r A(Q,r,T)\right)[|F_{1R}(r,T)|^2 + |F_{1L}(r,T)|^2], \quad (48)$$

$$G_A^{(2)}(Q^2,T) = 2g_Y\int_0^{\infty} e^{-\varphi(r,T)} dr A(Q,r,T)\, 2v(r,T) F_{1L}(r,T) F_{1R}(r,T). \quad (49)$$

The axial-vector form factor $G_A\ (Q^2,T)$is equal to the sum of these three terms.

The square of the average value of the axial-vector radius $r_A^2(T)$ for nucleons at finite temperature is obtained from the variation of the normalized axial-vector form factor with respect to Q^2 as shown below:

$$\langle r_A^2(T)\rangle = -\frac{-6dG_A(Q^2,T)}{G_A(Q^2,0)\mathrm{d}Q^2}. \quad (50)$$

To obtain the expression for the axial-vector transition form factor for nucleons at finite temperature, we consider nucleons excited in the state $\bar{\Psi}_{1,2}$ and ground state $\Psi_{2,1}$. The excited state of nucleons is represented by a profile function containing the quantum number $n = 1$ and mass $|p|' = m^*$. For the ground state nucleons, the profile function $F_{1,2L}^{(n)}$ is chosen with $n = 0$ and mass $|p| = m$.

The axial-vector transition form factor $G_{AT}^{(i)}(Q,T)$ is expressed as the sum of contributions from the temperature-dependent modifications to the form factor. For the addition to the nucleon's axial form factor $G_{AT}^{(0)}(Q^2,T)$, the following expression dependent on temperature is obtained[7]:

[7] Nasibova, N. Form factor of excited baryon at finite temperature / - Baku: Journal of Radiation Researches, - 2021. - 8, №1, - p. 36-41.

$$G_{AT}^{(0)}(Q^2,T) = \frac{1}{2}\int_0^\infty e^{-\varphi(r,T)} dr A(Q,r,T) \left[F_{1L}^{(n)*}(r,T) F_{1L}^{(m)}(r,T) - -F_{2L}^{(n)*}(r,T) F_{2L}^{(m)}(r,T)\right]. \quad (51)$$

For the addition to the nucleon's transition axial form factor $G_{AT}^{(1)}(Q^2,T)$ due to the magnetic-type interaction Lagrangian, and for the addition to the nucleon's transition axial form factor $G_{AT}^{(2)}(Q^2,T)$due to the Yukawa interaction Lagrangian, the following expressions are obtained:

$$G_{AT}^{(0)}(Q^2,T) = \frac{k_1}{2}\int_0^\infty e^{-\varphi(r,T)} dr\, r \left(\partial_r A(Q,r,T)\right) \left[F_{1L}^{(n)*}(r,T) F_{1L}^{(m)}(r,T) + F_{2L}^{(n)*}(r,T) F_{2L}^{(m)}(r,T)\right] \quad (52)$$

$$G_{AT}^{(1)}(Q^2,T) = 2g_Y \int_0^\infty e^{-\varphi(r,T)} dr A(Q,r,T)\, 2v(r,T) \left[F_{1L}^{(n)*}(r,T) F_{1L}^{(m)}(r,T) - - F_{2L}^{(n)*}(r,T) F_{2R}^{(m)}(r,T)\right] \quad (53)$$

The total expression for the axial-vector form factor for nucleons, denoted as $G_{AT}(Q^2,T)$ is determined as the sum of these three terms.

$$G_{AT}(Q^2,T) = G_{AT}^{(0)}(Q^2,T) + G_{AT}^{(1)}(Q^2,T) + G_{AT}^{(2)}(Q^2,T). \quad (54)$$

The temperature-dependent expression for the axial-vector transition radius at finite temperature is obtained from the corresponding form factor as follows:

$$\langle r_{AT}^2(T)\rangle = -\frac{-6dG_{AT}(Q^2,T)}{G_{AT}(Q^2,0)\mathrm{d}Q^2} \quad (55)$$

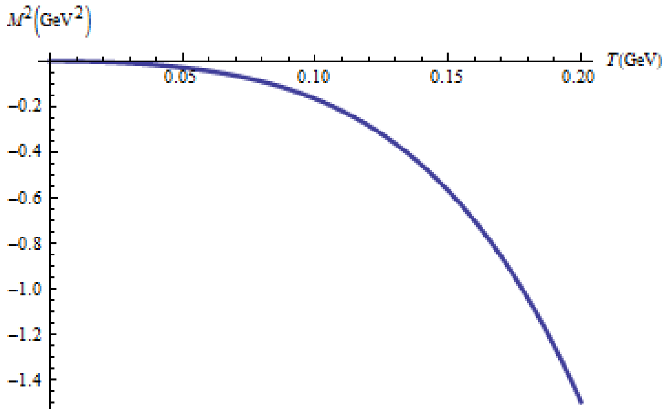

Figure 13. The temperature dependence of the effective mass of nucleon

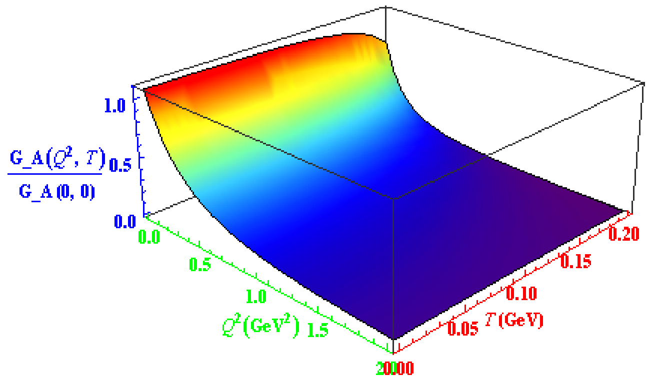

Figure 14. Dependence of the normalized axial vector form factor of nucleons in the ground state at α = 0.1 on temperature and the square of the transmitted momentum

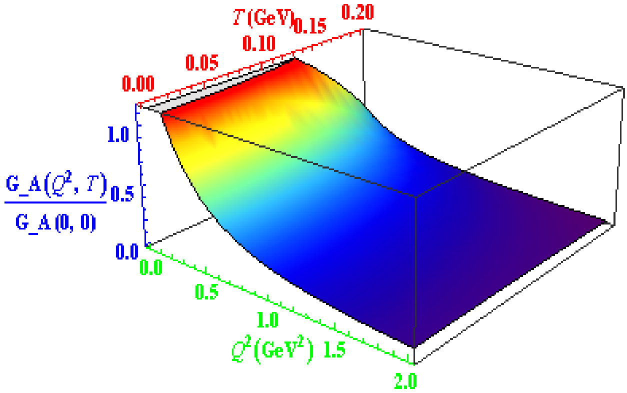

Figure 15. Dependence of the normalized axial vector form factor of nucleons in the ground state at α = 0.2 on the temperature and the square of the transmitted momentum

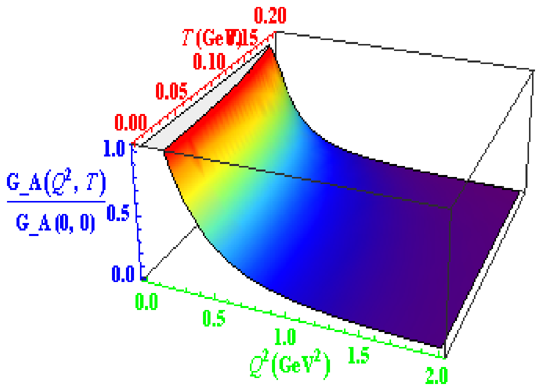

Figure 16. Dependence of normalized axial vector form factor of excited nucleons at α = 0.1 on temperature and square of transmitted momentum

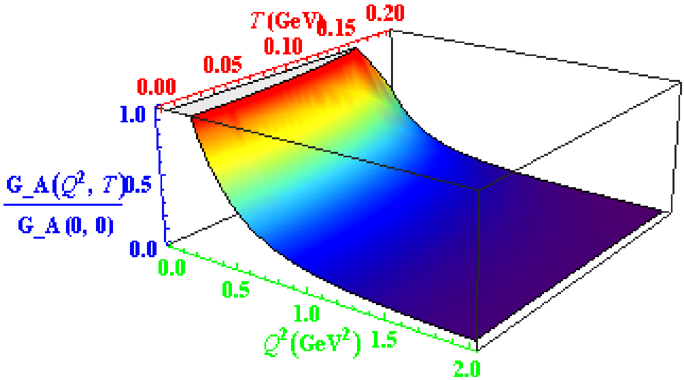

Figure 17. Dependence of the normalized axial vector form factor of excited nucleons at α = 0.2 on temperature and the square of the transmitted momentum

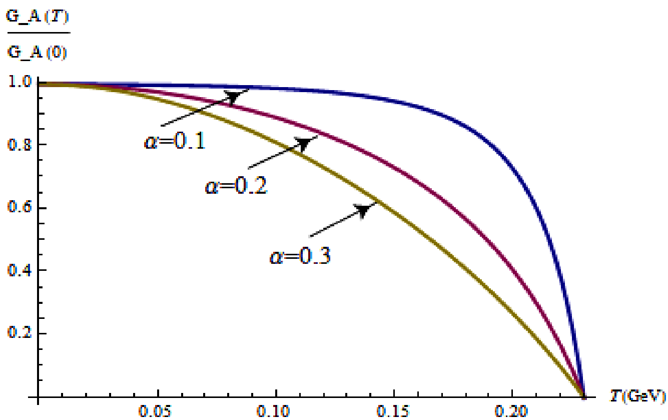

Figure 18. Temperature dependence of the normalized axial vector form factor of nucleons in the ground state at different values of α

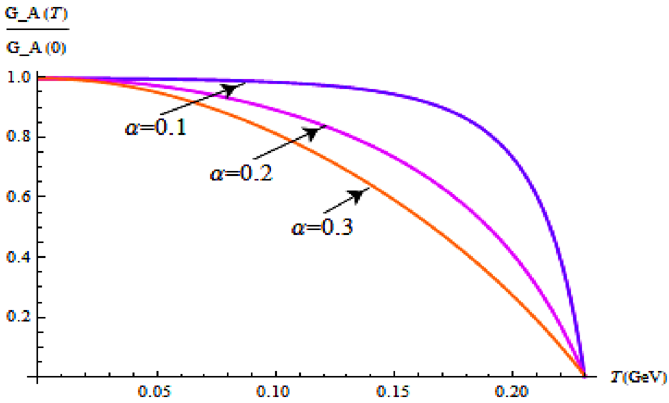

Figure 19. Temperature dependence of the normalized axial vector form factor of excited nucleons at different values of α

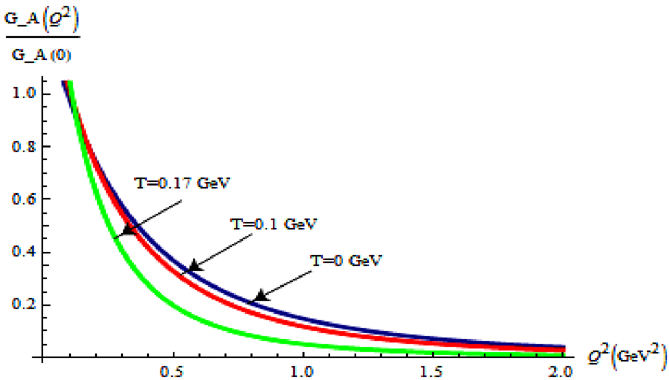

Figure 20. Dependence of the normalized axial vector form factor of nucleons in the ground state at different temperatures on the square of the transmitted momentum

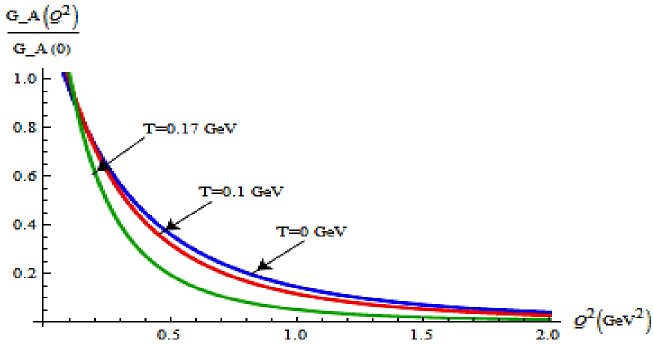

Figure 21. Dependence of the normalized axial vector form factor of the nucleon in the ground state at different values of temperature on the square of the transmitted momentum

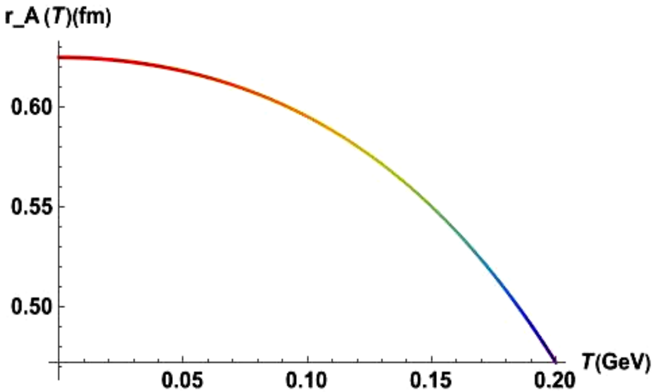

Figure 22. Dependence of axial vector radius of nucleons on temperature

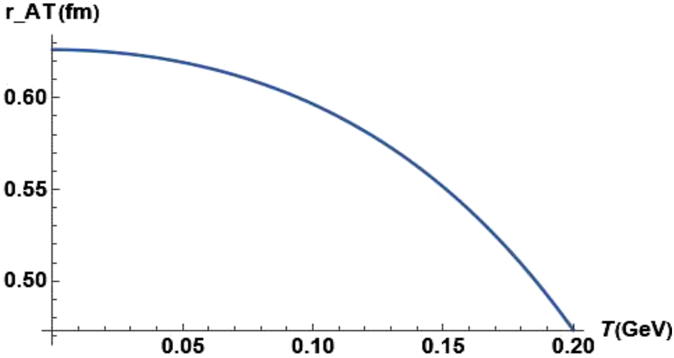

Figure 23. Dependence of axial vector transition radius of nucleons on temperature

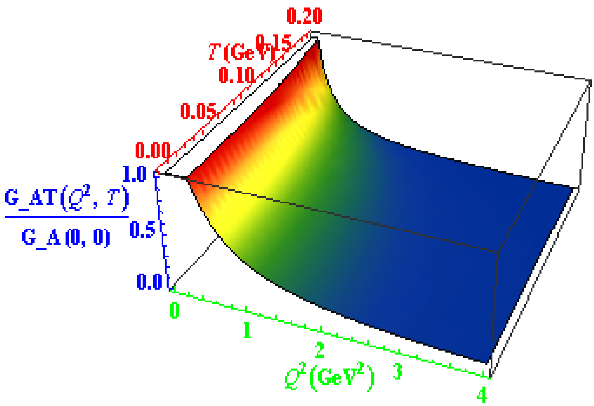

Figure 24. Dependence of the axial vector transition form factor on the temperature and the square of the transmitted pulse at $\alpha = 0.1$

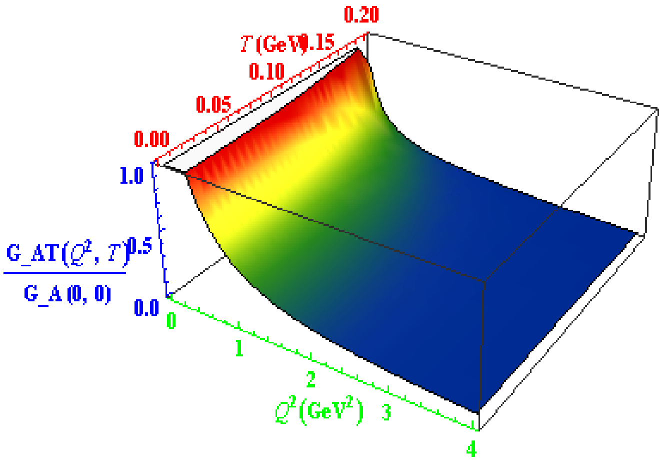

Figure 25. Dependence of the axial vector transition form factor on the temperature and the square of the transmitted momentum at α = 0.2

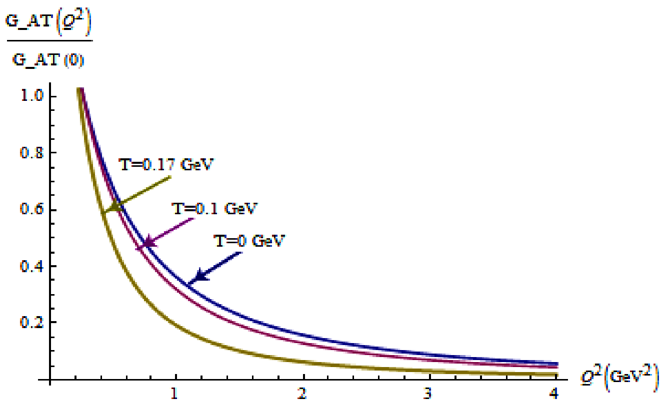

Figure 26. Dependence of the axial vector transition form factor on the square of the transmitted momentum at different values of temperature

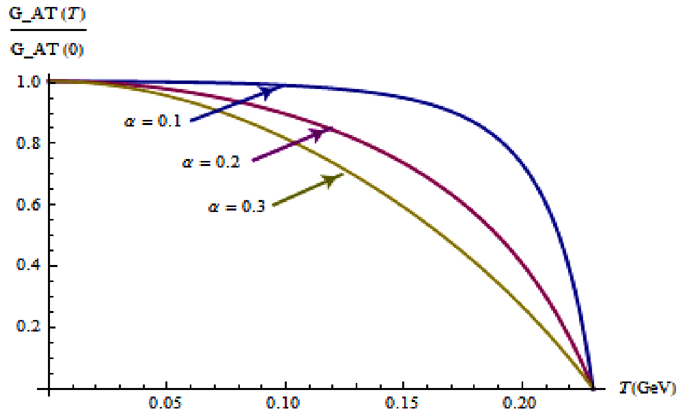

Figure 27. Dependence of axial vector transition form factor on temperature at different values of α

The Main Results of the Dissertation

1. For the first time, the temperature-dependent expressions of the ρ-meson-nucleon coupling constant in the holographic Soft Wall Model have been calculated theoretically, and it has been found that this constant decreases with increasing temperature, reaching zero near the critical temperature.
2. The isospin symmetry of the ω and ρ mesons is not broken at finite temperature.
3. The Rarita-Schwinger equation has been investigated for the first time at finite temperature in the Soft Wall Model. It has been obtained that the coupling constants of ρ, ω, a_1 meson-Δ baryon and ρ, ω meson-nucleon-Δ baryon decrease with increasing temperature.
4. As the temperature increases, the axial-vector form factor decreases. This implies a decrease in the probability of β decay with increasing temperature, which can be tested in neutrino experiments.
5. The result obtained for the axial-vector radius of nucleons at $T \to 0$ is close to experimental values and results from other models.
6. Although there is interaction between hhadrons below the temperature of confinement-deconfinement phase transition, above this

temperature, there is no interaction, and the fragmentation of all hhadrons and the replacement of the hhadron medium with a quark-gluon plasma medium can explain this phenomenon.

7. The result obtained for the a_1 meson-nucleon coupling constant in the Soft Wall Model at finite temperature is found to be close to values obtained from other models and experiments.

LIST OF SCIENTIFIC WORKS PUBLISHED ON THE SUBJECT OF DISSERTATION TOPIC

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2. Nəsibova, N. Sonlu temperaturda həyəcanlanmış vektor mezon və barionların minimal qarşılıqlı təsir sabiti // - Bakı: - Azərbaycan Fizika Jurnalı, - 2021. №1, - s. 47.
3. Nəsibova, N.Ə. Sonlu temperaturda ρ/a1 mezonun həyəcanlanmış halda olan barionlarla minimal qarşılıqlı təsir sabiti // - Bakı: Azərbaycan Milli Elmlər Akademiyasının Xəbərləri, Fizika-Texnika və Riyaziyyat Elmləri Seriyası, - 2021, №3, - s. 68-72.
4. Nəsibova, N.Ə. Sonlu temperaturda ω mezon-nuklon minimal qarşılıqlı təsir sabiti $g_{\omega NN}(T)$ // - Bakı: - Azərbaycan Fizika Jurnalı, - 2021. №3, - s. 34.
5. Nəsibova, N.Ə. Sonlu temperaturda a1 aksial mezonun həyəcanlanmış halda olan Δ barionlarla $g_{a_1 \Delta\Delta}(T)$ minimal qarşılıqlı təsir sabiti // - Bakı: - Azərbaycan Fizika Jurnalı, - 2021. №2, - s. 36-39.
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8. Mamedov, Sh. Axial-vector form factor of nucleons at finite temperature from the AdS/QCD soft-wall model / Sh. Mamedov, N. Nasibova // International Journal Modern Physics A, - Singapore: - 2023. - 38, №24, - p. 2350131.
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nucleon coupling constant from the AdS/QCD soft-wall model / Sh. Mamedov, N. Nasibova // Physical Review D, - College Park: - 2021. - 104, - p. 036010.
10. Nasibova, N. Form factor of excited baryon at finite temperature / - Baku: Journal of Radiation Researches, - 2021. - 8, №1, - p. 36-41.
11. Nasibova, N. Meson-delta and meson-nucleon-delta transition coupling constants in the soft-wall model of holographic QCD at finite temperature / N. Nasibova // Letters in High Energy Physics, 2022. - 326, - p. 31526.
12. Nasibova, N.A. Temperature Dependence of ω Meson-nucleon Coupling Constant from the AdS/QCD Soft-wall Model / İnternational journal Formal Science, - 2021. - 573, - p. 20210913.
13. Nasibova, N.A. Mamedov, Sh.A. Temperature dependence of ρ meson-nucleon coupling constant from the AdS/QCD soft-wall mode // Proceeding of the 2th International Conference on Holography and its Applications, - Damghan: - 25 January - 26 January, - 2023. – p. 57.
14. Nasibova, N.A., Mamedov, Sh.A. Axial-vector form factor of nucleons at finite temperature from the AdS/QCD soft-wall mode // Proceeding of the 1th International Conference on Holography and its Application, - Damghan: - 9 March - 10 March, - 2022. – p. 62.
15. Nasibova, N., Mamedov Sh. Axial-vector charge radius of nucleons in the soft-wall model of holographic QCD at finite temperature/ 8th International Conference MTP-2022: Modern Trends in Physics, - Baku: - 29 November - 01 December, - 2023. - 9, p. 32.
16. Nasibova, N.A. Minimal coupling constant of ρ meson Δ baryon interactions in the AdS/QCD soft wall model at finite temperature/ 7th International Conference MTP-2021: Modern Trends in Physics, - Baku: - 15 December - 17 December, - 2021. - p. 200-202.
17. Nasibova, N.A. Temperature dependence of ρ meson-nucleon coupling constant from the AdS/QCD soft-wall

model / World Congress on Quantum Physics 2022, J Laser Opt Photonics, ISSN: 2469-410X, Webinar, - Amsterdam: - 23 May – 24 May, -2022. – 8,- p. 6.

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