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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

STUDY OF THE INTERACTION OF MESONS AND NUCLONS IN THE MEDIUM AND VACUUM IN AdS/QCD MODELS

Speciality:	2212.01-Theoretical Physics
Field of Science:	Physics
Applicant:	**Shahnaz Ilgar Taghiyeva**

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The dissertation work was carried out at the Department of "Theoretical Physics" of Baku State University and the Department of "Theoretical Astrophysics and Cosmology" of the Shamakhi Astrophysical Observatory named after N.Tusi of the Ministry of Science and Education of the Republic of Azerbaijan.

Scientific supervisors: Candidate of Physical and Mathematical Sciences, Associate Professor
Shahin Alisattar Mammadov

Doctor of Physical and Mathematical Sciences, Professor
Tahmasib Mammad Aliyev

Official opponents: Corresponding Member of ANAS, Doctor of Physical and Mathematical Sciences, Professor
Ogtay Abil Samadov

Doctor of Philosophy in Physics, Associate Professor
Gulnara Hüseyn Guliyeva

Doctor of Philosophy in Physics
Ruslan Agharza Nuriyev

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

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

Scientific Secretary of the
Dissertation Council: Doctor of Philosophy in Physics
_______________ **Shahla Nabi Haciyeva**

Chairman of the
Scientific Seminar: Doctor of Physical and Mathematical Sciences, Professor
_______________ **Sarhaddin Qubaddin Abdullayev**

GENERAL DESCRIPTION OF WORK

Relevance and development of the topic. One of the important issues in elementary particle physics is the determination of the strong coupling constants and the transition form factors from the ground state to the excited state between elementary particles in medium and vacuum, in the ground and excited states. In the present dissertation, such issues are considered in the AdS/QCD (Anti de Sitter/Quantum Chromo Dynamics) models which based on the AdS/CFT (Anti de Sitter/Conformal Field Theory) correspondence. According to the AdS/CFT correspondence, the theory of gravity in the five-dimensional AdS space is matched with the gauge theory in the four-dimensional Minkowski space.

It should be noted that the AdS / CFT correspondence is of particular importance in the study of phenomenological problems in quantum chromodynamics. Such phenomenological problems include the determination of the lifetime of elementary particles, the determination of various types of decay and coupling constants, and also the determination of various types of form factors. The difficulties in solving these problems are due to the fact that since the strong coupling constant in the QCD takes large values at small values of the transmitted momentum, the S-scattering matrix theory is not applicable to the phenomenological problems of the strong interaction. It is precisely because of this difficulty that such problems are theoretically solved on the basis of non-excitation methods. The AdS/QCD models of the bottom-up holographic approach to the QCD do not impose any restrictions on the energy-momentum region transferred. Therefore, there are no large differences between the numerical values between the calculations determined by other non-excitation methods and experimental calculations in these models. For this reason, these models are of great theoretical importance in determining the coupling constants, various form factors, and in investigating quark-gluon plasma problems. From this point of view, in the current dissertation work, the hard and soft wall models of AdS/QCD were used to determine the coupling constants between mesons and baryons in medium and vacuum, as well as to determine the electromagnetic form factors for nucleon-excited nucleon transitions, and at the same time to investigate the electromagnetic properties of the nucleon in the excited state, and the capabilities of the "MATHEMATICA 9" package were used to perform calculations and visualize the determined results.

From the point of view of the degree of development of the dissertation work, it can be noted that the determination of the coupling constants between elementary particles has also been studied by other methods in other theoretical studies in medium and in vacuum. Currently, the results of experiments such as Jlab (Jeferson Lab) and MAMI (The Mainzer Microtron) are available for the precise determination of the electromagnetic interaction of the ground and resonance states of nucleons. However, these results must also be confirmed by modern theoretical studies. From this aspect, a number of authors have studied the Dirac and Pauli form factors, electric and magnetic form factors, helicity amplitudes, charges for protons and neutrons constituting the nucleon, magnetic radii, magnetic moment and the process of resonance electroproduction of nucleons in various models at zero and finite temperature. There are also experiments that experimentally study the distribution of charge in space within the nucleon, the electric and magnetic radii of protons and neutrons constituting the nucleon[12].

The problem of studying the interaction between elementary particles is of exceptional importance not only at zero temperature, but also at finite temperatures. Thus, the study of the properties of hadrons at finite temperatures plays an important role in understanding the early evolution of the Universe, the formation of hadronic matter and its phase transitions. These problems are considered in the holographic QCD, along with other models[3].

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Object and subject of research. The object of the research work is the octet meson and octet baryon. The subject of the research is to study the interaction constants and electromagnetic transition form factors corresponding to the octet meson-octet baryon interaction peaks.

Goals and objectives of the research. The main goal of the dissertation is to determine the coupling constants between mesons and baryons in hard and soft wall AdS/QCD models based on the AdS/CFT theory, at zero and finite temperatures, as well as to study the electromagnetic form factors of the nucleon-excited nucleon transition, the electromagnetic properties of the nucleon resonance states, and to compare the obtained results with known experimental facts and results obtained from other models. To achieve this goal, the following tasks were performed:

1. Obtaining mathematical expressions of electromagnetic form factors for nucleon-excited nucleon transitions in the hard wall model of AdS/QCD, determining helicity amplitudes, electric and magnetic form factors based on them, and determining their dependences on the square of the transmitted momentum;
2. Calculation of charge and magnetic radii for each of the $N + \gamma^* \to N^*(1440{,}1535{,}1710)$ transitions in hard wall AdS/QCD model;
3. Obtaining mathematical expressions of coupling constants between octet-meson-octet baryons in the hard wall model of AdS/QCD and calculating their numerical values;
4. Finding the coupling constants between the ρ-meson and the first excited nucleon for different values of the free parameters included in in hard and soft wall AdS/QCD models;
5. Investigation of the temperature-dependent variation of the a_1 and π-meson-nucleon coupling constants, and the a_1-meson decay constant, in soft-wall AdS/QCD model at finite temperature.

Investigation methods. In the dissertation work, the electromagnetic properties of the nucleon-excited nucleon transition, as well as the calculation of the interaction constants between mesons and baryons in the medium and in vacuum, were investigated framework the hard and soft wall AdS/QCD models, which are included in bottom-up approach of holographic QCD.

The main provisions submitted for defense:

1. The results for the Dirac and Pauli form factors are consistent with the MAID parameterization, CLAS experimental data, and the valence quark addition model in interval $1 < Q^2(GeV^2) < 5$ for $N + \gamma^* \rightarrow N^*(1440)$ transition. The MAID parameterization of the Dirac form factor of the negative-paired $N + \gamma^* \rightarrow N^*(1535)$ transition is consistent with the CLAS, JLab/Hall C experimental results, and also with the semi-relativistic approach starting at $Q^2 = 1.75\, GeV^2$. The results for the Pauli form factor are more consistent with the MAID parameterization, CLAS, and JLab/Hall C experimental results than with the semi-relativistic approach in hard-wall model for that transition, starting at $Q^2 = 1\, GeV^2$ The Dirac and Pauli electromagnetic form factors are agree with the MAID parameterization and CLAS experimental results starting from the values $Q^2 = 1.3\, GeV^2$ and $Q^2 = 0.8\, GeV^2$, respectively for the $N + \gamma^* \rightarrow N^*(1710)$ transition.

2. The dependence of the helicity amplitudes $A_{1/2}(Q^2)$, $S_{1/2}(Q^2)$ on Q^2 is in some agreement with the MAID parameterization, the CLAS experimental result, and the valence quark addition model for the $N + \gamma^* \rightarrow R(1440)$ transition. The dependence of the longitudinal $A_{1/2}(Q^2)$ helicity amplitude on Q^2 for the $N^*(1535)$ resonanse nucleon-nucleon transition is consistent with the experimental results, PDG data and the semi-relativistic model, starting from the value of the square of the transferred momentum $Q^2 = 0.25\, GeV^2$ and the transverse $S_{1/2}(Q^2)$ helicity amplitude on Q^2. The dependence of the helicity amplitudes $A_{1/2}(Q^2)$ and $S_{1/2}(Q^2)$ on Q^2 is consistent with the experimental results and non-relativistic quark model for the $N + \gamma^* \rightarrow N^*(1710)$ transition.

3. The $G_E(Q^2)$ curves are in agreement with the experimental results and with the results obtained within the light front holographic model for the $N + \gamma^* \rightarrow R(1440)$, $N + \gamma^* \rightarrow N^*(1710)$ nucleon resonances. Starting from the value of the square of the transmitted momentum of the magnetic form factor $G_M(Q^2)$ $Q^2 = 0.5\, GeV^2$, the results obtained in hard wall model for both transitions are in

agreement with the experimental results and the results given by the light front holographic model.

4. The results obtained for the numerical values of the charge and magnetic radii of protons and neutrons for the $N+\gamma^{*} \rightarrow N^{*}(1440,1535,1710)$ transitions in hard wall AdS/QCD model differ slightly from the results given by the soft wall model and experiments for the ground case.

5. For the first time, the values of the K-meson-octet baryon coupling constants have been determined, and neither experimental nor theoretical results are available for these coupling constants. It has also been established that the values of the interaction constants between the ρ-meson and ω-meson-octet baryons in hard-wall AdS/QCD model are agree with the results of the U&A and ESC models.

6. The numerical values of the coupling constants have been calculated between the π-meson and octet baryons in hard-wall model AdS/QCD coupling. The results obtained for $g_{\pi NN}$ and $g_{\pi\Sigma^0\Sigma^0}$ are agree with the chiral soliton model, and the result obtained for the $g_{\pi\Xi^0\Xi^0}$ coupling constant is agree with the QCD sum rule.

7. The coupling constants between the ρ-meson and the first excited state of the nucleon in hard and soft-wall AdS/QCD models are considerably larger than the numerical values calculated for the ground state of the nucleon.

8. In the finite temperature case, in soft-wall AdS/QCD model, the coupling constants between a_1 and π- mesons and nucleons decrease with increasing temperature and become zero near the critical temperature. This corresponds to the decay of $a_1$and π-mesons into quarks and gluons at the critical temperature. The a_1-meson decay constant decreases with increasing temperature and becomes zero near the critical temperature.

Scientific novelty of the research. It was studied for the first time in dissertation work:

1. Analytical expressions of electromagnetic form factors were obtained for the positive pair $N+\gamma^{*} \rightarrow N^{*}\,(1440,1710)$ and negative pair $N+\gamma^{*} \rightarrow N^{*}\,(1535)$ transitions in the hard wall model of AdS/QCD, and their dependences on the square of the transmitted momentum were studied.

2. Helicity amplitudes, electric and magnetic form factors were determined based on the Dirac and Pauli form factors in hard wall AdS/QCD model, and their dependences on the square of the transmitted momentum were established.

3. The numerical values of the proton and neutron, charge and magnetic radii were determined for $N+\gamma^* \rightarrow N^*(1440, 1535, 1710)$ transitions, and the electromagnetic properties of the resonance states of the nucleon were investigated.

4. The mathematical expressions of the coupling constants between octet-meson-octet baryons in hard-wall AdS/QCD model have been determined and their numerical values have been calculated.

5. The coupling constants have been found between the ρ-meson and the first excited nucleon in hard and soft-wall AdS/QCD models;

6. The temperature dependences of the a_1 -meson-nucleon and π-meson-nucleon coupling constants, as well as the a_1 -meson decay constant have been determined framework soft-wall AdS/QCD model at finite temperature

The theoretical and practical significance of the research. The obtained results in the dissertation work for the electromagnetic form factors for nucleon-excited nucleon transitions in vacuum, octet meson-octet baryons, ρ −meson-first excited nucleon, and in the finite temperature case, the coupling constants between a_1-meson-nucleon and π-meson-nucleon can be used to calculate the effective cross sections. The calculation of these effective cross sections is of particular importance in the study of the strong interaction of elementary particles. Since it is planned to calculate the coupling constants between elementary particles in excited state at the CEBAF (Continuous Electron Beam Accelerator Facility), the results obtained in this work for the coupling constant between the ρ-meson and the first excited nucleon can be theoretically taken as a benchmark. Also, the theoretical results obtained in the dissertation can be compared theoretically to the experimental values determined for the coupling constants at the Large Hadron Collider at the European Center for Nuclear Research.

Approbation and application. The main provisions and results of the dissertation work were discussed at the following conferences and scientific seminars and published in their materials:

- Internship program for young scientists on the topic of “Innovation Management” (Dubna, Russia, September 19-27, 2017);
- VI International Conference on “Control and Optimization with Industrial Applications” (BSU, July 11-13, 2018, Baku);
- VII International Conference on “Modern Trends in Physics” (BSU, December 15-17, 2021);
- I International Conference on “Holography and its Applications” (Iran, Damghan University, March 9-10, 2022);
- “Universal Observatory” scientific seminar of the Shamakhi Astrophysical Observatory (May 18, 2022);
- Scientific seminar of the Faculty of Physics, Baku State University (May 25, 2022);
- Scientific seminar of the Council of Young Scientists and Specialists (ANAS, September 23, 2022);
- International Conference “Days of Dynamics of Central Asia and the Caucasus” (BSU, September 28-30, 2022);
- Virtual International Conference “Living Universe - From Planets to Galaxies” (ETN, ShAO, October 12-14, 2022);
- II International Conference “Holography and its Applications” (Iran, Damghan University, January 25-26, 2023);
- Scientific seminar of the Institute of Physics Problems (BSU, March 2, 2023);
- “Universal Observatory” scientific seminar of the Shamakhi Astrophysical Observatory (April 12, 2023);
- Scientific seminar of the Institute of Physics (May 11, 2023);
- VIII International Conference “Modern Trends in Physics” (BSU, November 30-December 1, 2023);
- Extended Seminar of the General Observatory and Young Scientists and Specialists of the Shamakhi Astrophysical Observatory (May 3, 2024);
- “Computer Science and Gravitation-2024” International Conference (Khazar University, August 19-23, 2024).

The name of the organization where the dissertation work was performed. The dissertation work was carried out at Baku State

University and Shamakhi Astrophysical Observatory of the Ministry of Science and Education of the Republic of Azerbaijan.

Personal attendance of the author: The transmitted impulse intervals were found in holographic theory for which the transition form factors correspond to the experimental results. The temperature dependence of the coupling constant of the axial vector meson with nucleons was determined theoretically. Theoretical values of the strong coupling constants were calculated for several particles in holographic theory.

Publications. 14 scientific works have been published which related to the topic of the dissertation work - 9 scientific paper and 3 conference materials, 2 theses.

The total volume of the dissertation with a character including a separate volume of the structural units of the dissertation. The dissertation work consists of 180 pages, including an introduction, four chapters, a conclusion, a list of used literature, as well as a list of abbreviations and conventional symbols. The main part of the work (excluding figures, tables and a list of used figures) consists of 179435 marks (Introduction-17866, Chapter I-38614, Chapter II-41341, Chapter III-48344, Chapter IV-30950, Conclusion-2320). The list of literature used in the dissertation includes 152 sources cited, 22 figures and 7 tables reflecting the results.

THE CONTENT OF THE DISSERTATION

The introduction reflects information about the relevance and degree of development of the topic, the goals and objectives of the research, research methods, approval and application of the dissertation work, the structure and volume of the work, the main content of the dissertation, the volume of the structural sections of the dissertation separately, and the total volume of the dissertation with a mark. Also, the scientific novelty of the research, the theoretical and practical significance of the dissertation work, and the main provisions put forward for defense are explained.

The first chapter provides general information about the Einstein equation, AdS spacetime and AdS/CFT correspondence, classification of elementary particles, Schwarzschild metric, black hole, and correspondence between the laws of thermodynamics.

In the second chapter, information on the determination of the profile functions of nucleons in hard-wall AdS/QCD model and the expression of the bulk-to-boundary propagator is given for vector field in great detail. Then, the mathematical expressions of the Dirac and Pauli form factors were determined for $N+\gamma^* \to N^*$ transitions. Based on these form factors, the expressions of the electric and magnetic form factors, helicity amplitudes were determined, and were plotted graphs of the dependence of each of them on the square of the transmitted momentum. Also, the charge and magnetic radii of the proton and neutron were found for these transitions and the electromagnetic properties of the nucleon-excited nucleon transitions were revealed. The obtained results were compared to the results experimental and a number of theoretical models.

five-dimensional action is used to determine the coupling constants and form factors, in hard and soft wall models:

$$S_{int.} = \int d^4x\, dz e^{-\varphi(z)} \sqrt{g} L_{int}(x,z). \quad (1)$$

The generating function space is equal to the exponent of the action in AdS:

$$Z_{AdS} = e^{iS_{int}}. \quad (2)$$

It is known that in the boundary QCD theory, the average value of the vector current J_μ of nucleons with respect to vacuum is determined by the formula below:

$$\langle J_\mu \rangle = -i \frac{\delta Z_{QCD}}{\delta V_\mu(q)}\bigg|_{V_\mu=0} = -i \frac{\delta e^{iS_{int.}}}{\delta V_\mu(q)}\bigg|_{V_\mu=0} \quad (3)$$

The electromagnetic current for the nucleon-excited nucleon transition is expressed as follows:

$$J_\mu = \bar{u}_f(P_f)\left[\gamma_\mu^T F_1^{fi}(Q^2) + \frac{1}{m_{fi}}\sigma_{\mu\nu}q_\nu F_2^{fi}(Q^2)\right]u_i(P_i). \quad (4)$$

The VEV of the vector current of nucleons is determined based to formula (3) using the generating function (2). The following integral expressions are defined by comparing the expression of the four-dimensional (3) vector current of nucleons to the expression of the electromagnetic current for the nucleon-excited nucleon transition (4) for the Dirac and Pauli form factors of the $N + \gamma^* \to N^*$transition:

$$G_1(Q^2) = \frac{1}{2}\int_0^{z_m} dz V(Q,z) \sum_\tau c_\tau^{N^*N}(F_{\tau,0}^L(z)F_{\tau,1}^L(z) + F_{\tau,0}^R(z)F_{\tau,1}^R(z)), \quad (5)$$

$$G_2(Q^2) = \frac{1}{2}\int_0^{z_m} dz V(Q,z) \sum_\tau c_\tau^{N^*N}(F_{\tau,0}^R(z)F_{\tau,1}^R(z) - F_{\tau,0}^L(z)F_{\tau,1}^L(z)), \quad (6)$$

$$G_3(Q^2) = \frac{1}{2}\int_0^{z_m} dz \partial_z V(Q,z) \sum_\tau c_\tau^{N^*N}(F_{\tau,0}^L(z)F_{\tau,1}^L(z) - F_{\tau,0}^R(z)F_{\tau,1}^R(z), \quad (7)$$

$$G_4(Q^2) = \frac{M}{2}\int_0^{z_m} dz V(Q,z) \sum_\tau c_\tau^{N^*N}(F_{\tau,0}^L(z)F_{\tau,1}^R(z) + F_{\tau,1}^L(z)F_{\tau,0}^R(z)) \quad (8)$$

The Dirac and Pauli form factors $F_1(Q^2)$, $F_2(Q^2)$ are determined formed from the integrals (5)-(8) for the $N + \gamma^* \to N^*$ transition by the expressions:

$$F_1(Q^2) = G_1(Q^2) + g_V G_2(Q^2) + \eta_V G_3(Q^2), \quad (9)$$

$$F_2(Q^2) = \eta_V G_4(Q^2) \quad (10)$$

The electric and magnetic-Sachs form factors are determined after determining the electromagnetic form factors $F_{1,2}(Q^2)$ in $N + \gamma^* \to N^*$ transitions for the proton and neutron which are alternative Lorentz invariant quantities:

$$G_E^{P,N}(Q^2) = F_1^{P,N}(Q^2) - kF_2^{P,N}(Q^2), \tag{11}$$

$$G_M^{P,N}(Q^2) = F_1^{P,N}(Q^2) + F_2^{P,N}(Q^2). \tag{12}$$

The charge and magnetic radii of the proton and neutron are defined after determining the electric and magnetic form factors for the $N + \gamma^* \to N^*$ transitions. The charge and magnetic radii of the nucleon are determined based on the electric and magnetic form factors by the following expressions:

$$r_E^2 = -6 \frac{dG_E(Q^2)}{dQ^2}\bigg|_{Q^2=0}, \tag{13}$$

$$r_M^2 = -6 \frac{dG_M(Q^2)}{dQ^2}\bigg|_{Q^2=0}. \tag{14}$$

The helicity amplitudes are found based on the Dirac and Pauli form factors. The helicity amplitudes can be used to determine the addition of the form factor to the interaction when the spin is taken into account. The longitudinal $A_{1/2}(Q^2)$ and transverse $S_{1/2}(Q^2)$ helicity amplitudes are expressed by the functions $H(Q^2)$:

$$A_{1/2}(Q^2) = -bH_{\frac{1}{2},1}(Q^2), \tag{15}$$

$$S_{1/2}(Q^2) = b\frac{|p|}{\sqrt{Q^2}}H_{\frac{1}{2},0}(Q^2). \tag{16}$$

Here $|p|$ is determined by the expression $|p| = \frac{\sqrt{Q_+Q_-}}{2M_{N^*}}$, and the $H(Q^2)$ functions are related to the $F_{1,2}(Q^2)$ form factors in the form:

$$H_{\pm\frac{1}{2},0}(Q^2) = \sqrt{\frac{Q_-}{Q^2}}\left(F_1(Q^2)M_+ - F_2(Q^2)\frac{Q^2}{M_{N^*}}\right), \quad (17)$$

$$H_{\pm\frac{1}{2},\pm 1}(Q^2) = -\sqrt{2Q_-}\left(F_1(Q^2) + F_2(Q^2)\frac{M_+}{M_{N^*}}\right). \quad (18)$$

Here $Q_\pm = M_\pm^2 + Q^2$; $M_\pm = M_{N^*} \pm M_N$. The longitudinal and transverse helicity amplitudes of the $N^*(1535)$ transition are determined by the electromagnetic form factors $F_{1,2}(Q^2)$ as:

$$A_{1/2}(Q^2) = 2A_R\left[F_1(Q^2) + \frac{M_{N^*} - M_N}{M_{N^*} + M_N}F_2(Q^2)\right], \quad (19)$$

$$S_{1/2}(Q^2) = -\sqrt{2}A_R(M_{N^*} + M_N)\frac{|q|}{Q^2}\left[\frac{M_{N^*} - M_N}{M_{N^*} + M_N}F_1(Q^2) - \tau F_2(Q^2)\right] \quad (20)$$

Here $A_R = \frac{e}{4}\sqrt{\frac{Q_+^2}{M_N M_{N^*} K}}$, M_{N^*}, M_N are the masses of resonance and ground state of the nucleon, respectively.

The dependences on Q^2 of electromagnetic form factors, spiral amplitudes, and Sachs form factors are shown for $N + \gamma^* \to N^*$ transitions in figs. 1-5 [12 s. 51-56] Also, the hard-wall model results (red line) were compared to experimental facts and from other theoretical models. It was found that the results of the AdS/QCD are consistent with the MAID parameterization, CLAS experimental data, and the results the valence quark addition model in the interval $1 < Q^2(GeV^2) < 5$. for the Dirac and Pauli form factors in $N + \gamma^* \to R(1440)$ transition The dependence of the helicity amplitudes on Q^2 are in some agreement with the MAID parameterization, CLAS experimental results, and the valence quark addition model in $R(1440)$ resonance state in fig. 2.

In Figure 3, the Dirac form factor agrees experimental results, as well as the semi-relativistic approach results starting from $Q^2 = 1.75\, GeV^2$ [9 s. 45-50] for $N + \gamma^* \rightarrow N^*(1535)$ transition. For that transition, our result for the Pauli form factor in hard-wall model is more consistent with the experimental results such as MAID parameterization, CLAS, and JLab/Hall C starting from $Q^2 = 1\, GeV^2$ than the semi-relativistic approach. In Figure 4, the dependence Q^2 of the $A_{1/2}(Q^2)$ helicity amplitude is consistent with the experimental results starting from $Q^2 = 0.25\, GeV^2$ and the $S_{1/2}(Q^2)$ helicity amplitude agree starting from $Q^2 = 1\, GeV^2$, as well as the PDG data and the semi-relativistic model result for the $N^*(1535)$ state. The Dirac and Pauli electromagnetic form factors and helicity amplitudes are consistent with the CLAS experimental data, MAID parameterization and non-relativistic quark model for $N + \gamma^* \rightarrow N^*(1710)$ transition.

The dependence of the electric and magnetic form factors on -Q^2 are shown for $N + \gamma^* \rightarrow R(1440)$ (blue line), $N + \gamma^* \rightarrow N^*(1710)$ (green line) in figure 5. $G_E(Q^2)$ is consistent with the experimental results and the results of the light front holography. The $G_M(Q^2)$ is consistent with the consistent with experimental results and those obtained by light front holography starting from the value of the square of the transmitted momentum square of the $Q^2 = 0.5\, GeV^2$ for both transitions in hard wall model. Our results is consistent with the MAID parameterization, PDG, CLAS experimental data and the result of the semi-relativistic approach for the electric form factor of $N + \gamma^* \rightarrow N^*(1535)$ and magnetic form factor in some agreement with the MAID parameterization and semi-relativistic approach for this transition.

The numerical values of the charge and magnetic radii for protons and neutrons is given at each of the $N + \gamma^* \rightarrow N^*\,(1440{,}1535{,}1710)$ transitions in Table 1 and are compared to the experimental data and, with the results the soft-wall model. It is found that there is very little difference between the numerical values of these radii and the experimental results which determined for the ground state and the numerical values framework soft-wall AdS/QCD model.

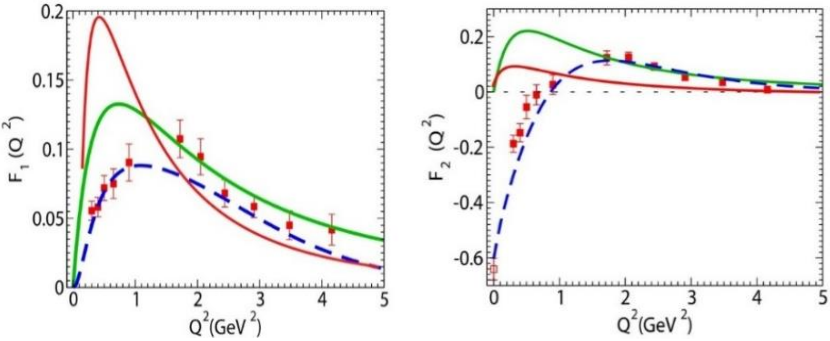

Figure 1. Comparison of the Dirac and Pauli form factors of the results MAID[4] (dashed curve) parameterization, CLAS[5] (red squares) experimental data and valence quark contribution[6] model for $N+\gamma^{*}\rightarrow R(1440)$

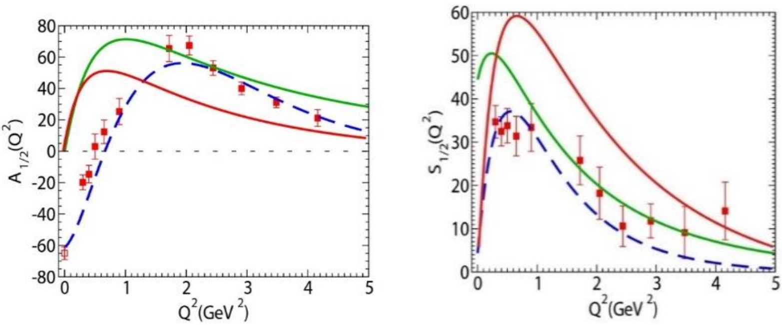

Figure 2. Comparison of the spiral amplitudes results of the MAID[4] (dashed curve) parametrization, CLAS[5] (red squares) experimental data and valence quark contribution [6] model for $N+\gamma^{*}\rightarrow R(1440)$

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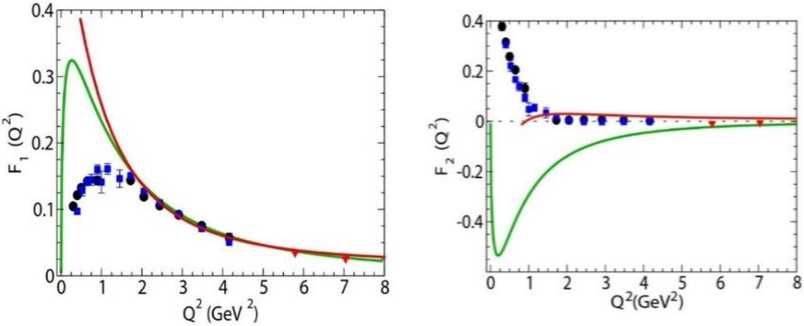
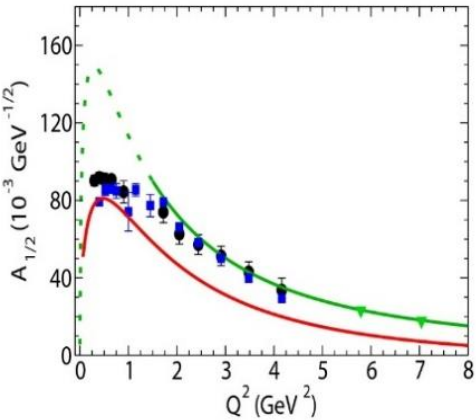


Figure 3. Comparison of Dirac and Pauli form factors (red curve) of the results MAID[7,8] (dashed curve) parameterization, CLAS[5] (red squares), the JLab/Hall C[9] experiments (triangles) and the semi-relativistic approach[10] for $N + \gamma^* \rightarrow N^*(1535)$



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[10] Ramalho, G. Semirelativistic approximation to the $\gamma^* N \rightarrow N(1520)$ and $\gamma^* N \rightarrow N(1535)$ transition form factors / Physical Review D, -2017, №5, -p. 054008-054021

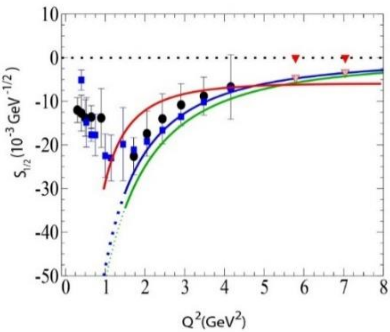

Figure 4. Comparison of spiral amplitudes (red curve) results of the MAİD[7,8] (dashed curve) parameterization, CLAS[6] (red squares), JLab/Hall C[9] (triangles), PDG[11] experiments and semi-relativistic approach[10] for $N + \gamma^{*} \rightarrow N^{*}(1535)$

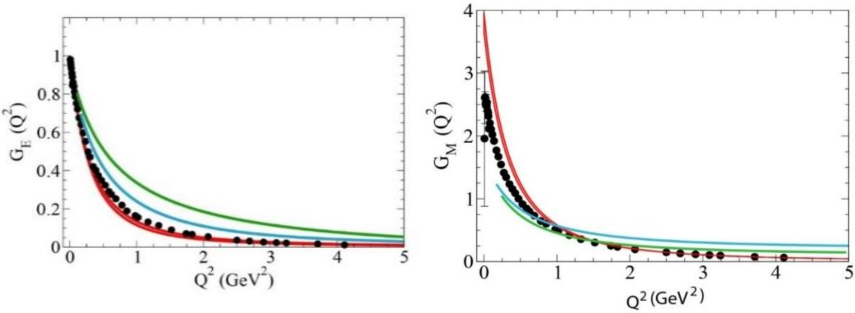

Figure 5. Comparison of the electric and magnetic form factors of the experimental results[1213] and light front holography[14] (red line) for $N + \gamma^{*} \rightarrow R(1440)$ (blue line) and $N + \gamma^{*} \rightarrow N^{*}(1710)$ (green line) transitions

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[11] Beringer, J. Review of particle physics / J.Beringer, J.F. Arguin, R.M. Barnett [et al.] // Physical Review D, -2012, № 1, 86,-p.010001-011525

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[13] Lachniet, J. A Precise measurement of the neutron magnetic form factor G_M^n in the few- GeV^2 region / J. Lachniet, H. Arenhövel, W. K. Brooks [et al.]// Physical Review Letters, -2009, №19, 102, -p. 192001-192006

[14] Ramalho, G. Valence quark contributions for the $\gamma^{*}N \rightarrow N(1440)$ form factors from light-front holography / Melnikov D. // Physical Review D, -2018, №3, 97, -p. 034037-034049

Table 1.
The electromagnetic properties of the resonance states of nucleon

(fm^2)	$R(1440)$	$N^*(1535)$	$N^*(1710)$	S/W [15]	PDG[16]	Exp. Res.
$\langle r_E^2\rangle^p$	0.8207	0.7722	0.6640	0.840	0.8768 ± 0.0069	
$\langle r_M^2\rangle^p$	0.687	0.638	1.109	0.785	0.777 ± 0.013 ± 0.010	0.831[17],[18]
$\langle r_E^2\rangle^n$	-0.566	-0.312	- 0.132	-0.117	-0.1161 ± 0.0022	-0.111[19]
$\langle r_M^2\rangle^n$	0.8207	0.7722	0.6640	0.792	$0.862^{+0.009}_{-0.008}$	0.864[20]

The third chapter provides some information about the inclusion of octet baryons in the hard-wall model of AdS/QCD. The determination of the wave functions is given in the fifth dimension for the octet meson and π-meson in hard-wall AdS/QCD model, also, the mathematical expressions of the profile functions is performed for the ρ-vector meson in the hard and soft-wall models and the wave function are reflected in the fifth dimension for the spinor field in the soft-wall model. The integral expressions of the

[15] Gutsche, T. Nucleon resonances in AdS/QCD / T. Gutsche, V.E. Lyubovitskij, I.Schmidt [et al.] // Physical Review D, -2013, №1, 87, -p. 016017-016027
[16] Nakamura, K. Review of particle physics / Journal of Physics G: Nuclear and Particle Physics, 2010, 37 (7A), -p. 075021-075022
[17] Bernauer, J. C. The electric and magnetic form factors of the proton / J. C. Bernauer, M.O. Distler, J. Friedrich [et al.] // Physical Review C, -2014, №1, 90, -p.015206-015243
[18] Arrington, J. Evaluation of the proton charge radius from e-p scattering /Sick I. // Journal of Physical and Chemical Reference Data, -2015, №3, 44, -p. 031204-031209
[19] Kelly, J. J. Simple parametrization of nucleon form factors / Physical Review C, -2004, №6, 70, -p. 068202-068204
[20] Zyla, P. A. Particle Data Group / P. A. Zyla, R.M. Barnett, J. Beringer [et al.] // Progress of Theoretical and Experimental Physics, -2020, 083C01, -p 1823-2014

coupling constants are obtained between the octet-meson and the octet-baryon, the π-meson-octet baryon, the ρ-meson and the first excited nucleon in these models, their numerical values are calculated, and these results compared to determined in other theoretical models.

The minimal interaction Lagrangian between the fermion currents of the vector field and the gauge field, the magnetic-type interaction Lagrangian between the spinors in the bulk space and the bulk vector field, and the interaction Lagrangian of the X-scalar field with the fermion-vector meson fields are defined, respectively, as following:

$$L^{(1)} = \bar{\Psi}_1 e_A^M \Gamma^A V_M \Psi_1 + \bar{\Psi}_2 e_A^M \Gamma^A V_M \Psi_2, \tag{21}$$

$$L^{(2)} = i k_1 e_A^M e_B^N (\bar{\Psi}_1 \Gamma^{AB} (F_L)_{MN} \Psi_1 - \bar{\Psi}_2 \Gamma^{AB} (F_R)_{MN} \Psi_2), \tag{22}$$

$$L^{(3)} = \frac{i}{2} k_2 e_A^M e_B^N (\bar{\Psi}_1 X \, \Gamma^{AB} (F_R)_{MN} \Psi_2 + \bar{\Psi}_2 X^+ \Gamma^{AB} (F_L)_{MN} \Psi_1). \tag{23}$$

The additions of the Lagrangians (21)–(23) to the interaction between the octet meson-octet baryons are defined as:

$$f^{(1)nm} = \int_0^{z_m} \frac{dz}{z^4} V_0(z) \left(\Phi_{1L}^{(n)*}(p', z) \Phi_{1L}^{(m)}(z) + \Phi_{2L}^{(n)*}(p', z) \Phi_{2L}^{(m)}(z) \right), \tag{24}$$

$$f^{(2)nm} = -2 \int_0^{z_m} \frac{dz}{z^3} V_0^{`}(z) k_1 \left(\Phi_{1L}^{(n)*}(p', z) \Phi_{1L}^{(m)}(p, z) - \Phi_{2L}^{(n)*}(p', z) \Phi_{2L}^{(m)}(p, z) \right) + k_2 \, v(z) \left(\Phi_{1L}^{(n)*}(p', z) \Phi_{2L}^{(m)}(p, z) + \Phi_{2L}^{(n)*}(p', z) \Phi_{1L}^{(m)}(p, z) \right), \tag{25}$$

$$f^{(3)nm} = 4m_b \int_0^{z_m} \frac{dz}{z^3} V_0(z) k_1 \Big(\Phi_{1L}^{(n)*}(p',z) \Phi_{1R}^{(m)}(p,z) - \Phi_{2L}^{(n)*}(p',z) \Phi_{2R}^{(m)}(p,z) \Big) + k_2\, v(z) \Big(\Phi_{1L}^{(n)*}(p',z) \Phi_{2R}^{(m)}(p,z) + \Phi_{2L}^{(n)*}(p',z) \Phi_{1R}^{(m)}(p,z) \Big). \quad (26)$$

To determine the coupling constant between the octet meson and the octet baryons, it is necessary to sum the additions (21)-(23) of interaction Lagrangians (24)-(26) to the octet meson-octet baryon interaction:

$$f^{nm} = f^{(1)nm} + f^{(2)nm} + f^{(3)nm}. \quad (27)$$

The Yukawa interaction Lagrangian was used to calculate the coupling constant between the π-meson-octet baryons:

$$\mathcal{L}_{Yukava} = -g_Y [\bar{B}_1 X B_2 + \bar{B}_2 X^+ B_1]. \quad (28)$$

The Z_{QCD} generating function is determined taking into account the Lagrangian (28) in action (1). According to the holographic principle, this generating function is identical to the Z_{QCD} generating function of the QCD in the boundary theory. Based on this identification, the VEV of the baryon current was found in the QCD by taking the variation of this generating function. The mathematical expression of the coupling constant between the π-meson-octet baryons is found by comparing the obtained current to the expressions of the current (4) in four-dimensional space:

$$g_{\pi-\text{o.b.}} = \int_0^{z_m} \frac{dz}{z^5} v(z) f(z) g_Y \big(\varphi_{1L}(p',z) \varphi_{2R}(p,z) + \varphi_{2R}(p',z) \varphi_{1L}(p,z) \big). \quad (29)$$

The gauge interaction Lagrangian of the fermion current and the vector field is established before determining the coupling constant between the ρ -meson and the first excited state of the nucleon:

$$L^{(1)} = \bar{N}_1 e_A^M \Gamma^A V_M N_1 + \bar{N}_2 e_A^M \Gamma^A V_M N_2. \quad (30)$$

Before writing the second interaction Lagrangian, we note that the nucleons described by the internal spinor fields in the ultraviolet limit have a magnetic moment. Therefore, in 5-dimensional space, a limit analogous to the magnetic moment is written for the spinor fields, and they can interact with this “moment” of the internal vector field. It is clear that in the boundary QCD this interaction will give a certain addition to the ρ-meson-nucleon interaction. The Lagrangian of this interaction can be given by the following expression [1 s. 252-254]:

$$L^{(2)} = ik_1 e_A^M e_B^N (\bar{N}_1 \Gamma^{AB} (F_L)_{MN} \, N_1 - \bar{N}_2 \Gamma^{AB} (F_R)_{MN} N_2). \quad (31)$$

In addition to the Lagrangian of the interaction between fermions and vector fields (31) in calculation of the magnetic typemoment, there is also a more complex form of interaction. This interaction also involves the internal scalar field X, and this lagrangian is expressed as:

$$L^{(3)} = \frac{i}{2} k_2 e_A^M e_B^N (\bar{\Psi}_1 X \, \Gamma^{AB} (F_R)_{MN} \Psi_2 + \bar{\Psi}_2 X^+ \Gamma^{AB} (F_L)_{MN} \Psi_1) \quad (32)$$

We determine the generating function after making certain calculations taking into account the expressions of the interaction Lagrangians (30)-(32) in action (1). Then, by VEV of the current in the ultraviolet limit based on expression (3), and comparing it to the expression of the nucleon current

$$J = c_{\rho NN} \bar{u}(p') \gamma_\mu u(p) \quad (33)$$

the following integral expressions of the additions of the lagrangians (30)-(32) to the $c_{\rho NN}$-ρ -meson-nucleon interaction are obtained [2 s.45-46]:

$$c^{(1)nm} = \int_0^{z_m} \frac{dz}{z^4} V_0(z) \left(f_{1L}^{(n)*}(z) f_{1L}^{(m)}(z) + f_{2L}^{(n)*}(z) f_{2L}^{(m)}(z) \right), \quad (34)$$

$$c^{(2)nm} = -2\int_0^{z_m} \frac{dz}{z^3} \grave{V_0}(z)[k_1 \left(f_{1L}^{(n)*}(z) f_{1L}^{(m)}(z) - f_{2L}^{(n)*}(z) f_{2L}^{(m)}(z)\right) +$$

$$+k_2\, v(z) \left(f_{1L}^{(n)*}(z) f_{2L}^{(m)}(z) + f_{2L}^{(n)*}(z) f_{1L}^{(m)}(z)\right), \qquad (35)$$

$$c^{(3)nm} = 4m_b \int_0^{z_m} \frac{dz}{z^3} V_0(z)[k_1 \left(f_{1L}^{(n)*}(z) f_{1R}^{(m)}(z) - f_{2L}^{(n)*}(z) f_{2R}^{(m)}(z)\right)$$
$$+k_2\, v(z) \left(f_{1L}^{(n)*}(z) f_{2R}^{(m)}(z) + f_{2L}^{(n)*}(z) f_{1R}^{(m)}(z)\right). \qquad (36)$$

The numerical value of the coupling constant between the $c_{\rho NN}$-ρ-meson and the first excited state of the nucleon is determined based on expressions (34)-(36) in holographic QCD, by the following formula:

$$c^{(q/t)nm} = c^{(1)nm} + c^{(2)nm} + c^{(3)nm}. \qquad (37)$$

In expressions (25), (26) and (29) of the coupling constants, free parameters such as $k, k_1, k_2,\ g_Y,\ m_q$ and σ are included. The numerical values of these parameters have been calculated in other theoretical works. Thus, the numerical value of the parameter k was obtained from the equality of the mass spectrum of the soft-wall AdS/QCD model for the a_1-meson-nucleon with the experimental values found for the mass of that particle, and the value of $k = 0.383\ GeV$ was used for the parameter k. The numerical values of the parameters k_1 and k_2 were found by fixing the numerical values of the interaction constants $g_{\rho NN}$ and $g_{\pi NN}$ in the hard wall model[21]. The numerical values of the parameters $z_m,\ \sigma,\ m_q$ were

[21] Ahn, H. C. Spin 3/2 Baryons and Form Factors in AdS/QCD / Hong D. K., Park C. // Physical Review D, -2009, №5, 80, -p.054001-054028

taken respectively, $z_m^{-1} = 0.323\ GeV$, $\sigma = (0.327)^3 GeV^3$ and $m_q = 0.00229\ GeV$, $g_Y = 9.182$[22].

Table 2

***ω* -meson-octet baryon coupling constants**

Model	p, n	Λ	Σ_s	Ξ_s
f^{nm}	1.22	4.867	1.139	0.387
U&A[23]	1.99			
YN[24]	3.317	2.211	2.211	
Bonn model[25]	4.472	2.981	2.796	
ESC model[26]	3.5452	2.8158	2.0863	2.0863

In Table 2-3, a comparative analysis of the experimental values obtained by our calculations for the coupling constants between the octet meson and the octet baryons as well as the results obtained from the soft-wall AdS/QCD model, as well as the U&A, YN, ESC and Bonn models, has been carried out. The coupling constants between the ρ-meson and the octet baryons $f_{\rho NN}$ is in some agreement with the result obtained from the U&A model and the soft-wall AdS/QCD model. The coupling constants between the ρ-meson and the Σ_s , Ξ_s octet baryons are agree with the numerical values obtained from the ESC model. The numerical values of the coupling constants between the K-meson and the octet baryons were determined theoretically for

[22] Hong, D. K. The Electric Dipole Moment of the Nucleons in Holographic QCD / D. K. Hong, H. C Kim, S. Siwach [et al.] // Journal of High Energy Physics, -2007. №11, -p. 036-057

[23] Adamuscin, C. Numerical values of f^F, f^D, f^S coupling constants in SU(3) invariant interaction Lagrangian of vector-meson nonet with ½⁺ octet baryons / C. Adamuscin, E. Bartos , S. Dubnicka [et al.]. // Physical Review C, -2016. № 5, 93, -p. 055208-055224

[24] Haidenbauer, J. Jülich hyperon-nucleon model revisited / Meißner U. G. // Physical Review C, -2005, №4, 72, -p. 044005-044227

[25] Holzenkamp, B. A meson exchange model for the hyperon-nucleon interaction / Holinde K., Speth J. // Nuclear Physics A, -1989. №3, 500, –p. 485-528

[26] Rijken, T. A. Baryon-Baryon Interactions:- Nijmegen Extended-Soft-Core Models / Nagels M. M., Yamamoto Y. // Progress of Theoretical Physics Supplement, -2010, №185, p. 14-71

the first time in hard-wall AdS/QCD model and since there are neither theoretical nor experimental results for these coupling constants, a comparison of the results obtained was not carried out. Regarding the coupling constants between ω-meson-octet baryons, the values obtained for $f_{\omega NN}$ are consistent with the numerical values calculated based on the U&A model. The result obtained for the coupling constant between ω-meson-Λ-baryon is consistent with the numerical value determined based on the Bonn model. It should be noted that different models have obtained different results for this coupling constant. The numerical values found for the constants $f_{\omega\Sigma\Sigma}$ and $f_{\omega\Xi\Xi}$ are in some agreement with the results obtained from the ESC model.

The results π-meson-octet baryon coupling constants are compared to the results obtained from the chiral soliton model, the QCD sum rule, the hard-wall model of AdS/QCD, the ESC, Bonn and YN (The Jülich hyperon (Y) nucleon (N) model) models in table 3 [4 s.160-165]. As can be seen from the table, the numerical values of the coupling constant between the π-meson and the nucleon are different for hard-wall model and other models. The numerical value is close the result chiral soliton model for the coupling constant $g_{\pi\Sigma^0\Sigma^0}$, and between the π-meson and Ξ^0-baryon coupling constant is consistent with the result QCD sum rule result**.**

Table 3

π −meson-octet baryon coupling constants [13 s. 660-666]

Model	$g_{\pi NN}$	$g_{\pi\Sigma^0\Sigma^0}$	$g_{\pi\Xi^-\Xi^-}$	$g_{\pi\Xi^0\Xi^0}$
$g_{\pi-o.b.}$	2.941	3.516	2.516	2.4799
Kiral soliton[27]	3.524±0.012	$3{,}356 \pm 0{,}014$	1.164± 0.004	−0.985±0.015
QCD sum rule[28]		$2{,}8 \pm 0{,}3$		$2{,}4 \pm 0{,}2$
Hard wall[29]	1.76			

[27] Yang G. S., Meson–baryon coupling constants of the SU(3) baryons with flavor SU(3) symmetry breaking / Kim H. Ch // Physical Letters B, -2018, № , 785, -p. 434-440

[28] Aliev T. M., Strong transitions of decuplet to octet baryons and pseudoscalar mesons / Azizi K., Savcıa M. // Nuclear Physics A, -2010, №1-2, 847, -p.101-117

[29] Kim H. Ch., Mesons and nucleons from holographic QCD in a unified approach / Journal of High Energy Physics, -2009, №11, -p.034-048

Table 3 follows

ESC model[25]	3,639	3.290		−1.475
YN[30] Bonn[31]	3.795	3.036		

Between the ρ-meson and the excited nucleon coupling constants are shown shown in hard-wall and soft wall in table 4-5 respectively.The calculations were performed at the values of the z_m^{-1} parameter $z_m^{-1} = 0.4\ GeV,\ z_m^{-1} = 0.6\ GeV.$ The calculations were carried out for two different values of the parameters k_1 and k_2, which are $k_1 = -0.98\ GeV^3,\ k_2 = 1.25\ GeV^3$ and $k_1 = -0.78\ GeV^3$, $k_2 = 0.5\ GeV^3$ [3 s. 38-42].

Note that since the first excited state of the nucleon was considered when studying the interaction between the ρ-meson and the nucleon in hard and soft wall models, it was not possible to compare the results obtained. However, it can be noted that since we are considering the excited state, the numerical values of the ρ-meson-nucleon coupling constant should be larger than the values calculated in the ground state.

Table 4

ρ-meson-nucleon coupling constant in hard-wall model

z_m^{-1}	$c^{(1)nm}$	$c^{(2)nm}$	$c^{(3)nm}$	$c^{(q/t)nm}$	
0.4	0.96359	4.29	−1.40	3.85	$2,52 \pm 0,06$[32]
0.6	1.01	8.86	1.37	11.24	$4,2 \sim 6,5$[33][34]

[30] Haidenbauer, J. Jülich hyperon-nucleon model revisited / Meißner U. G. // Physical Review C, -2005, №4, 72, -p. 044005-044227

[31] Holzenkamp, B. A meson exchange model for the hyperon-nucleon interaction / Holinde K., Speth J. // Nuclear Physics A, -1989. №3, 500, –p. 485-528

[32] Stoks, V.G.J. Meson-baryon coupling constants from a chiral-invariant SU(3) Lagrangian and application to NN scattering / Nuclear Physics A, -1997, №4, 613, -p. 311-341

[33] Hohler, G. The ϱNN vertex in vector-dominance models / Pietarinen E. // Nuclear Physics B, -1975, №2, 95, -p. 210-230

[34] Gross, F. High-precision covariant one-boson-exchange potentials for np scattering below 350 MeV / Stadler A. // Physical Letters. B, -2007, № 4-5, 657, -p. 176-179

Table 5

***ρ*-meson-nucleon coupling constant in soft-wall model**

Soft wall model	$c^{(1)}$	$c^{(2)}$	$c^{(3)}$	$c^{(q/t)}$		
$k_1 = -0.98$	2.48	3.11	10.25	15.84		14.36[23]
$k_1 = -0.78$	0.98	1.39	4.25	7.65	6.78[35]	

The finding of profile functions was considered for mesons and baryons in soft-wall AdS/QCD model at finite temperature in **fourth chapter**. At the same time, the temperature-dependent variation of the a_1-meson-nucleon and π-meson-nucleon coupling constants and the a_1-meson decay constant was studied in that model. When studying the temperature dependence of the a_1-meson-nucleon coupling constant, the following interaction Lagrangians were used:

a) Minimal gauge interaction Lagrangian

$$L^{(0)} = \frac{1}{2}[\bar{\Psi}_1 \Gamma^M A_M \Psi_1 - \bar{\Psi}_2 \Gamma^M A_M \Psi_2]; \quad (38)$$

b) Magnetic-type gauge interaction Lagrangian

$$L^{(1)} = \frac{i}{2}[\bar{\Psi}_1 \Gamma^{MN} F_{MN} \Psi_1 + \bar{\Psi}_2 \Gamma^{MN} F_{MN} \Psi_2]; \quad (39)$$

c) Interaction Lagrangian between spinors, axial vector field and scalar field

$$L^{(2)} = g_\gamma[\bar{\Psi}_1 X \Gamma^M A_M \Psi_2 + \bar{\Psi}_2 X^\dagger \Gamma^M A_M \Psi_1]. \quad (40)$$

The integral expressions of a_1 meson-nucleon interaction additions corresponding to the interaction Lagrangians (38)-(40) and the coupling constant based on these expressions are determined by the following expressions at finite temperature, in soft wall model:

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[35] Huseynova, N. ρ meson-nucleon coupling constant from the soft-wall AdS/QCD model / Mamedov A. Sh. // International Journal Theoretical Physics 54, -2015, №10, -p. 3799-3809

$$g^{(0)}_{a_1NN}(T) = \frac{1}{2}\int_0^\infty \frac{dr}{r^4} A_0(r,T)(|\phi_{1R}(r,T)|^2 - |\phi_{1L}(r,T)|^2), \quad (41)$$

$$g^{(1)}_{a_1NN}(T) = \frac{k_1}{2}\int_0^\infty \frac{dr}{r^3} \partial_r A_0(r,T)(|\phi_{1R}(r,T)|^2 + |\phi_{1L}(r,T)|^2), \quad (42)$$

$$g^{(2)}_{a_1NN}(T) = 2g_\gamma \int_0^\infty \frac{dr}{r^4} A_0(r,T) v(r,T) \phi_{1R}(r,T) \phi_{1L}(r,T), \quad (43)$$

$$g_{a_1NN}(T) = g^{(0)}_{a_1NN}(T) + g^{(1)}_{a_1NN}(T) + g^{(2)}_{a_1NN}(T). \quad (44)$$

Also, the temperature dependence of the a_1-meson decay constant was determined in soft-wall model and its temperature dependence graph was constructed. For this, the result obtained during the determination of the mass spectrum of the ρ-meson was used. The profile function is determined for the a_1-meson in soft-wall model at finite temperature by the following expression:

$$v_n(r,T) = \Psi(r,T)\sqrt{\frac{2n!}{(1+n)!}} L_n^1\big(\Psi(r,T)\big), \quad (45)$$

Thus, using the expression for the decay constant of the zero-temperature state

$$F^2 = \frac{1}{g_5^2}[(v_n''0)]^2 \quad (46)$$

the temperature-dependent variation of the decay constant was determined at finite-temperature for the axial-vector meson:

$$F_{a1}^2(r,T) = \frac{1}{g_5^2}[|A_n''(r,T)|_{r=0}]^2. \quad (47)$$

To determine the mathematical expression of the π-meson-nucleon coupling constant at finite-temperature, the following Lagrangian of the pion-nucleon interaction $\mathcal{L}_{\pi NN}$ was used:

$$\mathcal{L}_{\pi NN} = \bar{N}_1 \Gamma^r A_r N_1 - \bar{N}_2 \Gamma^r A_r N_2. \qquad (48)$$

In order to determine the pion-nucleon coupling constant through the (48) Lagrangian, certain mathematical calculations were performed on that expression, and the following expression was obtained:

$$g_{\pi NN}(T) = -\int_0^\infty \frac{c_\pi dr}{2r^4} f_0(r,T)(\varphi_{1L}^*(r,T)\varphi_{1R}(r,T) - \varphi_{2L}^*(r,T)\varphi_{2R}(r,T)). \qquad (49)$$

The temperature dependence graphs of the coupling and decay constants were constructed for different values of the quark spectrum and pseudoscalar meson decay constants $N_f = 2, F = 87\ MeV$; $N_f = 3, F = 100\ MeV$; $N_f = 5, F = 140\ MeV$, respectively.

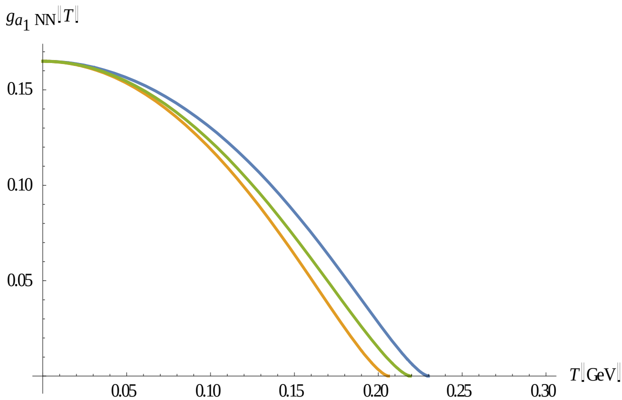

Figure 6. Comparison of the $g_{a_1 NN}(T)$ dependence at values $N_f = 2$ (orange line); $N_f = 3$ (green line); $N_f = 5$ (blue line) [7 s. 1080-1097]

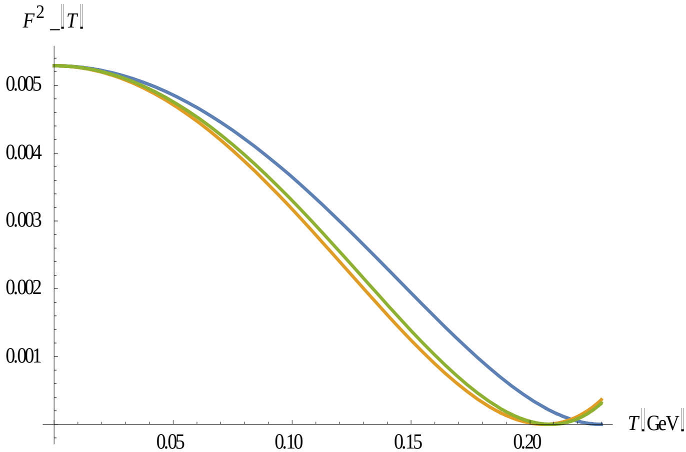

Figure 7. The temperature dependence of the a_1-meson decay constant ($N_f = 2$ (orange line); $N_f = 3$ (green line); $N_f = 5$ (blue line)

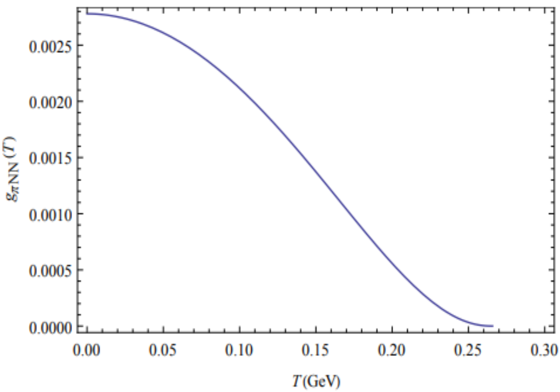

Figure 8. Temperature dependence of π-meson-nucleon coupling constant $g_{\pi NN}(T)$

As can be seen from the temperature dependences of the coupling constants and the decay constant in fig. 6-8, each of the coupling constants and the decay constant are equal to zero around the same temperature. This means that there is no interaction between hadrons after that temperature. At this temperature, hadrons melt and transform into quark-gluon plasma. Between π-meson and nucleon coupling constant is calculated using (49) formula in $T = 0$ case. We determined that the numerical value of the $g_{\pi NN}(T)$-coupling constant when assuming $T = 0$ is $g_{\pi NN}(T) = 2.8$ .This result is consistent with the numerical value $g_{\pi NN}(r, 0) = 2.94$ that we found for this coupling constant in the hard-wall model.

CONCLUSION

1. Mathematical expressions of the square of the transmitted momentum dependence of the electromagnetic form factors have been obtained for $N + \gamma^* \to N^*$ transition in hard-wall AdS/QCD model. It has been found that the Dirac and Pauli form factors agree with the experimental results for $N + \gamma^* \to R(1440)$ transition in interval $1 < Q^2(GeV^2) < 5$and $N^*(1710)$ resonance state at the values of $Q^2 = 1.3\, GeV^2$; $Q^2 = 0.8\, GeV^2$, and corresponds with the experimental values and the semi-relativistic approach model at energies above $Q^2 = 1.75\, GeV^2$ for $N + \gamma^* \to N^*(1535)$ transition.

2. The dependence of the spiral amplitudes on Q^2in the nucleon-excited nucleon transition has been studied and it has been shown that the results obtained in the hard wall model are agree with the MAID parameterization, the valence quark addition model and the CLAS experimental data for $R(1440)$, semirelativistic model, with the PDG data with in $N^*(1535)$ state, and agrer with the results of the $N^*(1710)$ experimental and nonrelativistic quark model.

3. It has been established that the dependence of the electric and magnetic form factors on the square of the transferred momentum is $1/Q^n$form for the $N + \gamma^* \to N^*(1440, 1535, 1710)$ transitions.

4. For the first time, it has been found that there is very little difference between the values of the nucleon charge and magnetic radii for the $N + \gamma^* \to N^*(1440, 1535, 1710)$ transitions and the experimental and theoretical results found in the ground case.

5. The octet meson-octet baryon coupling constant was calculated framework hard-wall model AdS/QCD model, and it was found that the numerical values of the coupling constants between ρ-meson and ω-meson-octet baryons are agree with the results of the U&A, ESC models. Also, for the first time, theoretical values were obtained for the coupling constants between K-meson-octet baryons.

6. The numerical values of the π-meson-octet baryon coupling constants were calculated within hard-wall AdS/QCD model, and it was found that the coupling constants $g_{\pi NN}$ and $g_{\pi\Sigma^0\Sigma^0}$ are close with the results of the chiral soliton model, and the numerical value of the coupling constant $g_{\pi\Xi^0\Xi^0}$ is agree the results of the QCD sum rule.

7. The coupling constant between the ρ −meson and the first excited state of the nucleon was calculated in hard and soft-wall AdS/QCD models and it was shown that the numerical value of this constant is larger than the experimental and theoretical values calculated for the ground state of the nucleon.

8. Theoretically, for the first time, the temperature dependences of the coupling constants between the a_1 and π-mesons and the nucleon, and the a_1-meson decay constant were studied in the soft-wall model of AdS/QCD at finite temperature. It was determined that as the temperature increases, these coupling constants and the decay constant decrease, and these constants become equal to zero at a value close to the critical temperature.

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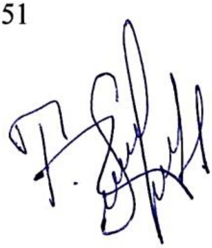

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Address: Baku city, AZ 1148, Z. Khalilov str. 23, Baku State University, main building.

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