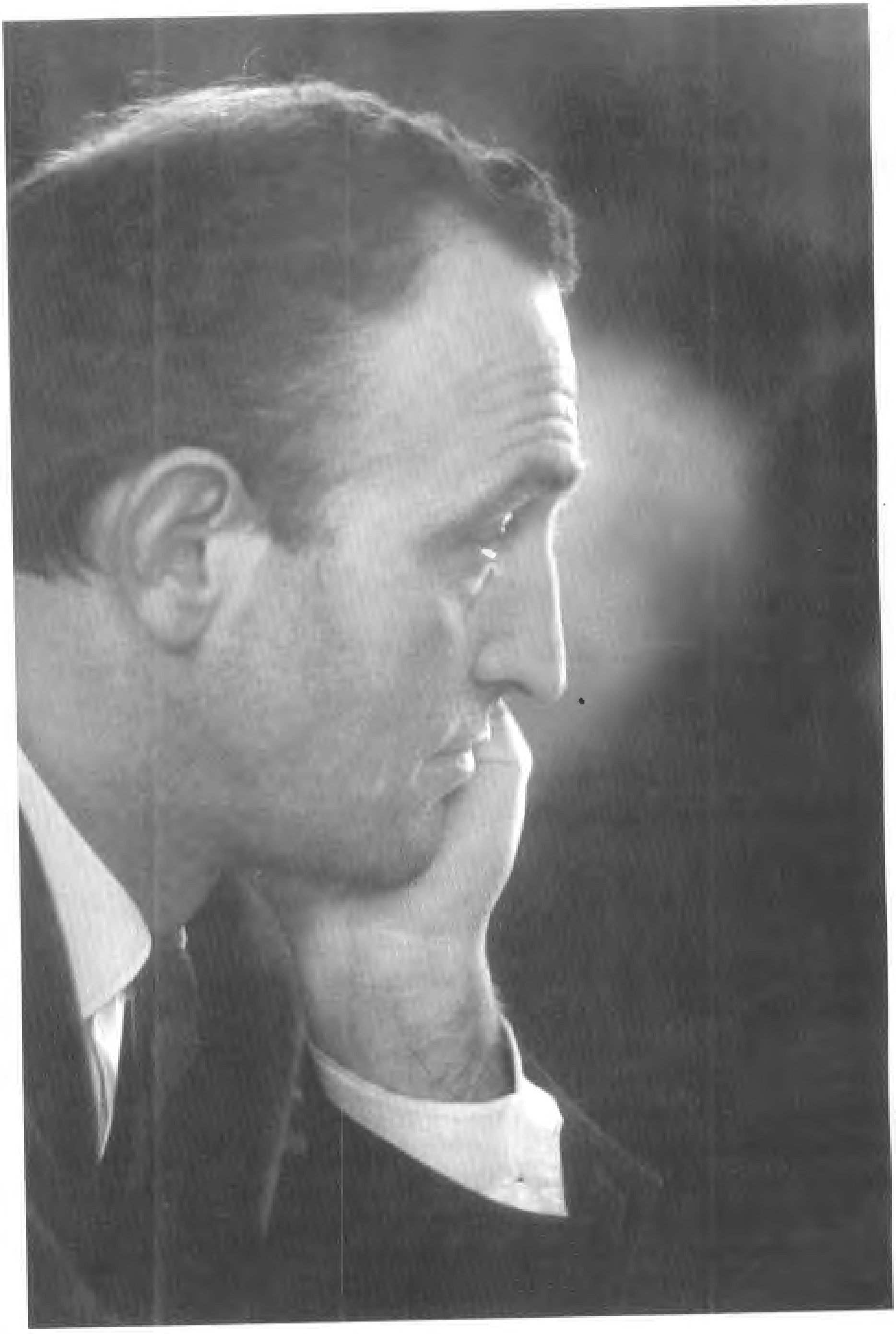
A.N.Tavkhelidze



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PREFACE

This collection has been prepared for the 70th birthday of Academician Albert Nikiforovich Tavkhelidze, a theoretical physicist of world recognition. The collection contains a short essay on the life and activities of the scientist, a full list of his scientific works together with their classification in accordance with the respective lines of research. Of these numerous publications the collection includes two lectures delivered by A.N. Tavkhelidze 35 years ago at the famous Seminar on High-Energy Physics and Elementary Particles (Trieste, International Centre for Theoretical Physics (ICTP), 3 May – 30 June 1965), where he was invited by the ICTP director Professor Abdus Salam. In these lectures presented for the first time was the Bogoliubov–Tavkhelidze dynamic approach to the construction of hadrons from *quasifree quarks*, possessing a new quantum number – *colour*, that underlies modern quantum chromodynamics.

CONTENTS

Lecture One

HIGHER SYMMETRIES AND COMPOSITE MODELS OF ELEMENTARY PARTICLES

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1. INTRODUCTION

Recently, group theoretical methods based on the synthesis of internal symmetry and space-symmetry properties have been extremely successful in the investigation of elementary particles properties.

There are two points of view in the application of group theoretical methods in the theory of elementary particles. According to the first one, all particles are considered as equally elementary. Another point of view suggests that there are some fundamental particles carrying all symmetry properties (as quarks, trions, Schwinger model, etc.), and all physical particles are considered as bound states of these. The composite model, in the $SU(6)$ frame, is much like the Wigner model of nuclear shells, combining spin independence and isotopic invariance of nuclear forces and classifying all nuclear states by different representations of the $SU(4)$ group. The difference consists in that we are not sure that particles representing the fundamental representation of $SU(3)$ exist at all. However, the plausibility of the idea of composite models of elementary particles attracts attention of many physicists.

Our aim is to discuss the simplest dynamical model and to investigate in the framework of this model the form factors and magnetic moments of baryons and mesons. This paper is in fact a review of investigations performed by Bogolubov et al. [1]. In order to illustrate the nature of the problems mentioned above, and as an introduction to the discussion of a relativistic model of composite particles, we shall first consider a nonrelativistic model, where the particles are regarded as bound states of the quarks.

Such a consideration may be justified by the following arguments. Examination of the relations predicted by $SU(6)$ suggests that the interaction, leading to formation of bound states, weakly depends on spin, and a good agreement of mass formulae with experimental data confirms an idea that masses of fundamental particles are large compared to the symmetry-breaking perturbation.

We shall show also that the small Dirac magnetic moment of the quark nevertheless could lead (due to the enhancement mechanism) to large moments of known baryons.

In the next part of our review we shall consider relativistic models of composite particles and their electromagnetic form factors.

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2. BOSONS

Consider a nonrelativistic model where the particles are regarded as bound states of the quarks. The wave functions of the quarks are the fundamental six-dimensional representation (sixtets) of $SU(6)$. It is well known that the members of the sixtet are $SU(3)$ triplets, each member having spin 1/2.

We denote the wave function of a quark by $\psi_a = \psi_{i,A}$ where $i = 1,2$ is a spin state index and $A = 1,2,3$ is the $SU(3)$ index. For zero energy quark we have

$$\psi_a = t_A \chi_i$$
$$\chi_1 = \binom{1}{0} \; \chi_2 = \binom{0}{1}, \tag{2.1}$$

t_A denotes the $SU(3)$-triplet. Thus for each A we have a two-component function ψ_a.

The transformation property of antiquark wave function is given by a conjugated representation of $SU(3)$ group. We denote the wave function of an antiquark by ψ^b, and for zero energy we have $\psi^{i,A} = \chi^{i} t^A \chi^i = \epsilon^{iK}\chi_K$.

Regarding a meson as a bound state of quark and antiquark, we denote the wave function of meson by ψ^b_a. The problem is to write down the equation for ψ^a_b.

To get such an equation we use the following assumption:

(a) we assume that the interaction which leads to a formation of bound states is weakly dependent on spin and unitary spin;

(b) the internal motion of a quark is regarded as nonrelativistic.

Taking into account the remarks which we made above, in zero approximation, where spin and unitary spin dependence is neglected, for the mesons we may write down the quasipotential equation which in the centre-of-mass system has the following form

$$(E^2 - H_0(r))\psi^b_a(r) = 0. \tag{2.2}$$

H_0 depends only on the relative co-ordinate $\vec{r}^{\,2} = (\vec{r}_1 - \vec{r}_2)^2$.

As H_0 is a scalar function, the energy spectrum for all 36 mesons is the same. In general, the perturbation which removes this degeneracy may depend on spin and unitary spin simultaneously. We assume that there are two types of perturbations: the first removes the degeneracy with respect to spin and the other with respect to unitary spin. We neglect the interference terms; they are supposed to be of second order in the perturbation.

The perturbation term which depends on spin may be represented in the following form

$$H_1\psi^{jB}_{iA} = [(\vec{S}_i + \vec{S}_j)^2 V_1(r) + V_1'(r)]\psi^{jB}_{iA} + [(\vec{S}_i + \vec{S}_j)^2 V_2(r) + V_2'(r)]\psi^{jA}_{iA}. \tag{2.3}$$

The operators $\vec{S}_i$, $\vec{S}_j$ are the spin operators for the quark and antiquark, correspondingly. We use the designation

$$\begin{aligned} \vec{S}_i\psi^{jB}_{iA} &\equiv \vec{S}^{i'}_i \psi^{jB}_{i'A}, \\ \vec{S}_j\psi^{jB}_{iA} &= \vec{S}^{j}_{j'}\psi^{j'B}_{iA}. \end{aligned} \tag{2.4}$$

In order to write down a perturbation eliminating the unitary spin degeneracy we use the main idea of Zweig [2], viz., we assume that the mass of the quark t_3 is different from those of t_1

and t_2:

$$m_A^2 = m_0^2 + \Delta m^2 \delta_A^3 = \left(m_0^2 + \frac{1}{3}\Delta m^2\right) - (\lambda_8)_A \Delta m^2.$$

The perturbation which could give such a splitting may be chosen by analogy with Eq.(2.5)

$$H_2 \psi_a^b = W(r)[(\lambda_8)_A + (\lambda_8)_B]\psi_a^b. \tag{2.5}$$

The matrices $(\lambda_8)_A$ act on the index A and $(\lambda_8)_B$ on the index B:

$$\begin{aligned} (\lambda_8)_A \psi_a^b &= (\lambda_8)_A^{A'} \psi_{iA'}^{jB}, \\ (\lambda_8)_B \psi_a^b &= (\lambda_8)_{B'}^{B} \psi_{iA}^{jB'}. \end{aligned} \tag{2.6}$$

Taking into account the perturbation terms (2.3) and (2.4), we get

$$\begin{aligned} (E^2 - H_0)\psi_a^b &= [V_1(r)(\vec{S}_i + \vec{S}_j)^2 + V_1'(r)]\psi_{iA}^{jB} + \\ &+ [V_2(r)(\vec{S}_i + \vec{S}_j)^2 + V_2'(r)]\psi_{iA}^{jA} + \\ &+ W(r)[(\lambda_8)_A + (\lambda_8)_B]\psi_{iA}^{jB}. \end{aligned} \tag{2.7}$$

For the unperturbed solution we have

$$\psi_{iA}^{jB}(r) = \rho_{iA}^{jB}\psi(r), \tag{2.8}$$

where ρ_{iA}^{jB} is independent of r. After separating the spin and unitary spin structures we get

$$\rho_{iA}^{jB} = \begin{cases} V_A^B \chi_i^j & s = 1, \\ \rho_A^B \delta_i^j & s = 0, \end{cases} \tag{2.9}$$

s is the total spin of the system.

Since the perturbation terms conserve the total spin, Eq.(2.7) splits into two equations: one for spin 1 and the other for spin 0.

For the case of spin 1, we have 9 vector mesons:

$$V = \begin{pmatrix} \frac{1}{\sqrt{2}}(\rho_0 + \omega') & \rho^+ & K^{*+} \\ \rho^- & \frac{1}{\sqrt{2}}(\rho_0 - \omega') & \bar{K}^{*0} \\ K^{*-} & K^{*0} & \phi' \end{pmatrix}$$

$$V_1^2 = \rho^+, \quad V_2^1 = \rho^- \ldots \tag{2.10}$$

Using Eqs.(2.8) and (2.9) we see that to find the mass corrections to the vector mesons we must diagonalize the quadratic form

$$M^2 = \left(m_1^2 - \frac{a}{3}\right)\bar{V}_B^A \bar{V}_A^B + \frac{h_1}{3}\bar{V}_B^B \bar{V}_A^A + a(\bar{V}_3^A V_A^3 + \bar{V}_A^3 V_3^A). \tag{2.11}$$

Substituting Eq.(2.10) into Eq.(2.11) we get

$$\begin{aligned}
M^2 &= \left(m_1^2 - \frac{a}{3}\right)[\bar{\rho}^+\rho^+ + \bar{\rho}^-\rho^-\bar{\rho}^0\rho^0] + \\
&+ \left(m_1^2 + 2\frac{a}{3}\right)[\bar{K}^{*+}K^{*+} + \bar{K}^{*-}K^{*-} + \bar{K}^{*0}K^{*0} + K^{*0}\bar{K}^{*0}] + \\
&+ \left(m_1^2 - \frac{a}{3}\right)\bar{\omega}'\omega' + \left(m_1^2 - \frac{5}{3}a\right)\bar{\phi}'\phi' + \\
&+ \frac{h_1}{3}(2\bar{\omega}'\omega' + \bar{\phi}'\phi' + \sqrt{2}\bar{\omega}'\omega' + \sqrt{2}\bar{\phi}'\phi').
\end{aligned} \tag{2.12}$$

From this we see that

$$m_\rho^2 = m_1^2 - \frac{a}{3}, \quad m_{K^*}^2 = \left(m_1^2 + \frac{2}{3}a\right). \tag{2.13}$$

If we put $h_1 = 0$, we get

$$m_{\omega'}^2 = m_\rho^2 \quad \text{and} \quad m_{\phi'}^2 + m_\rho^2 = 2m_{K^*}^2. \tag{2.14}$$

If we want to calculate the masses of real ω and ϕ mesons, we must diagonalize the quadratic form

$$\left(m_1^2 - \frac{a}{3}\right)\bar{\omega}'\omega'\left(m_1^2 - \frac{5}{3}a\right)\bar{\phi}'\phi' + \frac{h_1}{3}[2\bar{\omega}'\omega' + \bar{\phi}'\phi' + \sqrt{2}\bar{\omega}'\phi' + \sqrt{2}\bar{\phi}'\omega']. \tag{2.15}$$

The eigenvalues of this form are given by the equation

$$\begin{vmatrix} m_1^2 - \frac{a}{3} + \frac{2h_1}{3} - \mu & \frac{\sqrt{2}}{3}h_1 \\ \frac{\sqrt{2}}{3}h_1 & m_1^2 - \frac{5}{3}a + \frac{h_1}{3} - \mu \end{vmatrix} = 0. \tag{2.16}$$

Excluding the parameters m_1^2, a, and h_1 we obtain the well-known formula of Schwinger [3].

$$(m_\omega^2 - m_\rho^2)(m_\phi^2 - m_\rho^2) = \frac{4}{3}(m_{K^*}^2 - m_\rho^2)(m_\phi^2 + m_\omega^2 - 2m_{K^*}^2). \tag{2.17}$$

Now we would like to give a brief survey of the situation concerning pseudoscalar mesons. To get the known mass formula it is sufficient to make replacements $m_1 \to m_0$, $h_1 \to h_0$, $\rho \to \pi$, $K \to K^*$, $\omega' \to \eta'$, $\phi' \to \eta''$. Then we have

$$m_\pi^2 = m_0^2 - \frac{a}{3}; \quad m_K^2 = m_0^2 + \frac{2}{3}a. \tag{2.18}$$

From this follows the Glashow formula

$$m_{K^*}^2 = m_\rho^2 = m_K^2 - m_\pi^2. \tag{2.19}$$

In order to avoid the mixing of unitary singlet and octet of pseudoscalar mesons, we choose from 36-meson states only 35 states which satisfy the conditions

$$\psi_a^a = 0. \tag{2.20}$$

We also require that the perturbation does not break this condition. For the perturbation matrix Γ this requirement leads to

$$\Gamma^{c,a}_{c,b} = 0. \tag{2.21}$$

This condition may be satisfied if we take the perturbation matrix in the following form

$$\Gamma^{iA;i'A'}_{jB;j'B'} = g^{iA;i'A'}_{jB;j'B'} - \frac{1}{6}\delta^A_B\delta^j_i g^{kc;i'A'}_{kc;j'B'}.$$

Then for the pseudoscalar octet we get

$$m_\eta^2 = m_0^2 + a$$

which leads us to the Gell-Mann–Okubo mass formula

$$m_\eta^2 = \frac{4}{3}m_K^2 - \frac{1}{2}m_\pi^2.$$

3. BARYONS

In our approach baryons are regarded as bound states of three quarks. Denote the wave function of the baryon by ψ_{abc}. In the zero approximation we write the following equation for baryons

$$(E - H_0)\psi_{abc} = 0. \tag{3.1}$$

We represent the perturbation terms in the following form

$$\begin{aligned} H\psi_{abc} &= [(\vec{S}_i + \vec{S}_j + \vec{S}_K)^2 W_1 + W_2']\psi_{iA,jB,kC} \\ &+ W_2[(\lambda_8)_A + (\lambda_8)_B + (\lambda_8)_C]\psi_{abc} \\ &+ W_3[(\lambda_8)_A P_{BC} + (\lambda_8)_B P_{AC} + (\lambda_8)_C P_{AB}]\psi_{iA,jB,kC}, \end{aligned} \tag{3.2}$$

the functions W depend only on a relative distance between the quarks, P_{AB} is the permutation operator. The third term carries on the exchange interaction for the octet.

There are three types of symmetries for the wave function with respect to the permutation of the unitary and spin indices: completely symmetric with 56 components, antisymmetric with 20 components and the function transforming under the two-dimensional representation of the permutation groups of three elements, 70 components.

As was shown in paper [4], a better relation between the magnetic moments is obtained for the function symmetric with respect to spin and unitary spin, 56 components.

However, if we assume that there are no additional quantum numbers, the space function must be completely antisymmetric which is impossible if the system is in the S-state.

A way out can be found if the quarks are supposed to obey parastatistics [5] or if we introduce additional quantum numbers which antisymmetrize the total wave function. Employing these additional quantum numbers we are able to make the quark charges integer without violating the relations between the magnetic moments.

Consider Eq.(3.1) with the perturbation (3.2) for the functions symmetric with respect to spin and unitary spin.

The perturbation term (3.2) conserves the total spin of the system, and the equation for the baryons splits into two equations: one — for spin 3/2 and the other — for spin 1/2. In the zero approximation, the baryons wave function can be represented in the form

$$\psi_{ABC}(r_1, r_2, r_3) = \varphi(r_1, r_2, r_3)\phi_{ABC}. \tag{3.3}$$

For the octet particles we have $\phi_{ai,bj,ck}$

$$\begin{aligned}
p &= \frac{1}{\sqrt{3}}\{\phi_{11,11,22} - \phi_{11,21,12}\}, \\
r &= \frac{1}{\sqrt{3}}\{\phi_{21,21,22} - \phi_{21,11,22}\}, \\
\Sigma^+ &= \frac{1}{\sqrt{3}}\{\phi_{11,11,32} - \phi_{11,31,12}\}, \\
\Sigma^- &= \frac{1}{\sqrt{3}}\{\phi_{21,21,32} - \phi_{21,31,22}\}, \\
\Sigma^0 &= \frac{1}{\sqrt{6}}\{2\phi_{11,21,32} - \phi_{11,31,22} - \phi_{21,31,12}\}, \\
\Lambda &= \frac{1}{\sqrt{2}}\{\phi_{11,31,22} - \phi_{21,31,12}\}, \\
\Xi^- &= \frac{1}{\sqrt{3}}\{\phi_{31,31,22} - \phi_{21,31,32}\}, \ \Xi^0 = \frac{1}{\sqrt{3}}\{\phi_{31,31,12} - \phi_{11,31,32}\}.
\end{aligned} \tag{3.4}$$

The functions ϕ_{ABC} are normalized by the condition

$$||\phi_{AAA}||^2 = 6, \quad ||\phi_{AAB}||^2 = 2, \quad ||\phi_{ABC}|| = 1.$$

Using the perturbation theory we obtain the following relations for the masses of baryons

$$m_\Sigma - m_N = a + b, \quad m_{\Xi^-} - m_N = 2a - b, \quad m_\Lambda - m_N = a - b. \tag{3.5}$$

From this, follows the Gell-Mann–Okubo mass formula

$$m_\Xi + m_N = \frac{3m_\Lambda + m_\Sigma}{2}. \tag{3.6}$$

For the decuplet particles we have

$$m_0 - m_{\Sigma^*} = m_{\Sigma^*} - m_{\Xi^*} = m_{\Xi^*} - m_{\Omega^-} = -a - b. \tag{3.7}$$

Thus, for the mass splitting in the octet and decuplet we get

$$m_\Sigma - m_N = m_{\Sigma^*} - m_0. \tag{3.8}$$

It is easy to write the perturbation which describes the electromagnetic mass splitting within the isotopic multiplets

$$\begin{aligned}
H_2\psi_{abc} &= \{I_1(e_A^2 + e_B^2 + e_C^2) + I_2(e_Ae_B + e_Ae_C + e_Be_C) \\
&+ I_3(e_Ae_BP_{AB} + e_Ae_CP_{AC} + e_Be_CP_{BC})e\psi_{abc}\}.
\end{aligned} \tag{3.9}$$

The first term represents the electromagnetic corrections to the proper effective mass of the quarks; the second term, the direct electromagnetic interaction of the quarks; and the third term, the exchange interaction. Noting that $e_A^2 = \frac{2}{3} + \frac{1}{3}e_A$ we write down the electromagnetic perturbation as

$$\begin{aligned} H_2 &= \{I_1'(e_A + e_B + e_C) + I_2'(e_A + e_B + e_C)^2 \\ &+ I_3(e_A e_B P_{AB} + e_A e_C P_{AC} + e_B e_C P_{BC})\}\,\psi_{abc}. \end{aligned} \tag{3.10}$$

Using this interaction we get

$$\begin{aligned} m_p - m_n &= \alpha + \beta + \frac{1}{3}\gamma, \quad m_{\Sigma^+} - m_{\Sigma^-} = 2\alpha + \frac{2}{3}\gamma, \\ m_{\Xi^-} - m_{\Xi^0} &= -\alpha + \beta - \frac{1}{3}\gamma, \\ m_{\Delta^+} - m_{\Delta^0} &= m_{\Sigma^{*+}} - m_{\Sigma^{*0}} = \alpha + \beta + \frac{1}{3}\gamma, \\ m_{\Delta^-} - m_{\Delta^0} &= m_{\Xi^{*-}} - m_{\Xi^{*0}} = m_{\Sigma^{*-}} - m_{\Sigma^{*0}} = -\alpha + \beta + \frac{2}{3}\gamma, \\ m_{\Delta^{++}} - m_{\Delta^+} &= \alpha + 3\beta + \frac{4}{3}\gamma. \end{aligned} \tag{3.11}$$

From this we find the electromagnetic mass splitting in the octet

$$m_p - m_n + m_{\Sigma^-} - m_{\Sigma^+} = m_{\Xi^-} - m_{\Xi^0}. \tag{3.12}$$

We also get the relations between the electromagnetic mass splitting in octet and decuplet

$$m_p - m_n = -m_{\Delta^+} - m_{\Delta^0} = -m_{\Delta^-} - m_{\Delta^0} = m_{\Xi^{*+}} - m_{\Xi^{*0}}. \tag{3.13}$$

From $SU(6)$ symmetry follow relations between the magnetic moments of baryons. This is one of the important consequences of $SU(6)$ symmetry. Using the formulae of quantum mechanics for the relativistic composite model it is possible to calculate the magnetic moments of baryons.

Actually, choosing the magnetic moment operator in the form

$$\vec{\mu} = 3\mu[(e\vec{\sigma})_A + (e\vec{\sigma})_B + (e\vec{\sigma})_C] \tag{3.14}$$

one can easily show that the magnetic moments of the resonances are $3e\mu$ where e is the resonance charge, and for the baryon octet we have

$$\mu_p = 3\mu, \quad \mu_m = 2\mu, \quad \mu_{\Sigma^-} = -\mu. \tag{3.15}$$

The magnetic moments of other particles follow from the unitary symmetry relations

$$\mu_p = \mu_{\Sigma^+}, \quad \mu_n = 2\mu_{\Xi^0} = 2\mu_\Lambda = -2\mu_{\Sigma^0}. \tag{3.16}$$

In order to get the experimental value of the magnetic moment we must put μ equal to the nuclear magneton $\mu = e/2m$, where m is the mass of the bound states, that is, baryons.

Now we want to study a mechanism providing for such an enhancement of the magnetic moment of the quark.

Consider the bound states of the Dirac particle in the scalar field. We wish to calculate the magnetic moment of Dirac particles which are in the bound states.

Let us write the Dirac equation

$$[M + V(r) + \beta\vec{\alpha}\cdot(\vec{p} - e\vec{A})]u = E\beta u. \tag{3.17}$$

We consider the case

$$V(r) = \begin{cases} 0 & r > r_0 \\ -M + \alpha & r < r_0 \end{cases}. \tag{3.18}$$

Representing the spinor u in the form

$$u = \begin{pmatrix} \varphi \\ \chi \end{pmatrix} \tag{3.19}$$

we get the following equation for φ:

$$(M + V - E)\varphi + \vec{\sigma}(\vec{p} - e\vec{A})\frac{1}{M + E + V}\vec{\sigma}(\vec{p} - e\vec{A})\varphi = 0. \tag{3.20}$$

Taking into account only the first order terms in the electromagnetic interaction, we obtain the correction to the energy operator

$$\Delta\hat{E} = e\vec{\sigma}\cdot\vec{A}\frac{1}{M + E + V}\vec{\sigma}\cdot\vec{p} + e\vec{\sigma}\cdot\vec{p}\frac{1}{M + E + V}\vec{\sigma}\cdot\vec{A}. \tag{3.21}$$

Calculating the energy spectrum correction to the S-state, we arrive at the following expression for the magnetic moment

$$\mu = \frac{2e}{3}\int\limits_0^\infty \frac{g(r)}{M + E + V}\frac{dg}{dr}r^3\,dr, \tag{3.22}$$

where the function $W = rg$ satisfies the equation

$$W'' + (E^2 - M - V)W = 0. \tag{3.23}$$

Using the requirement that $W(r_0 - 0) = W(r_0 + 0)$ we obtain the equation for the energy spectrum of bound states

$$\frac{E - M}{r_0(E + M)(E + \alpha)} + \frac{1}{E + \alpha}\left(\frac{W'}{W}\right)_{r_0 - 0} = \frac{1}{E + M}\left(\frac{W'}{W}\right)_{r_0 + 0}. \tag{3.24}$$

Later on, the calculations are made for the case $M \to \infty$. Here the energy spectrum equation has the form

$$r_0(E^2 - \alpha^2)^{1/2}\operatorname{cotg} r_0(E^2 - \alpha^2)^{1/2} = 1 - r_0(E + \alpha). \tag{3.25}$$

Integrating Eq.(3.22) and taking the limit $M \to \infty$, we get

$$\mu = \frac{e}{6}\frac{4Er_0 + 2\alpha r_0 - 3}{2E^2 r_0 - 2E_0 + \alpha} \tag{3.26}$$

for the case $\alpha = 0$, numerical calculations give $Er_0 \sim 2$. Thus,

$$\mu \sim \frac{e}{2E}\frac{5}{6}. \tag{3.27}$$

If the proton is considered as a bound state of three quarks in the self-consistent field, the energy of each quark is equal to $E = m/3$. Using then (3. 27) for the magnetic moment of the proton we obtain a value for the nuclear magneton to be $\mu_Q \sim 2.5$. We have seen that the effective magnetic moment of Dirac particles which are in the bound states is determined by the bound state energy.

REFERENCES

1. Bogolubov, N.N., Struminski, B. and Tavkhelidze, A., JINR preprint D-1968, Dubna (1965);
   Bogolubov, N.N. and Chelest, W. et al., JINR preprint 0-2075, Dubna (1965);
   Bogolubov, N.N. et al., JINR preprint 2141, Dubna (1965).

2. Zweig, G., Phys. Lett. 8 (1964) 214;
   Gell-Mann, M., Phys. Rev. Lett. 8 (1964) 214.

3. Schwinger, J., Phys. Rev. Lett. 12 (1964) 237.

4. Struminski, B., JINR preprint 1939, Dubna (1965).

5. Greenberg, 0., Phys. Rev. Lett. 13 (1964) 598.

Lecture Two

ELECTROMAGNETIC FORM FACTORS IN COMPOSITE MODELS OF ELEMENTARY PARTICLES (RELATIVISTIC MODELS)

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1. INTRODUCTION

In our previous review we have considered the simplest variant of the dynamical approach to $SU(6)$ symmetry. Using the assumption that the mass of a quark is large we write down nonrelativistic $SU(6)$ symmetric equations which reflect mass relations obtained in $SU(6)$ and relations between magnetic moments. In the simplest example of a Dirac particle scalar field, the mechanism of the enhancement of the magnetic moment was shown.

It is of interest to write down relativistic invariant equations for composite particles which describe the enhancement of magnetic moments and produce the true electromagnetic form factors of elementary particles**.

Recently a number of very interesting results concerning form factors were given in the theory of Salam et al. [1] based on $\tilde{SU}(12)$ symmetry. However, in order to calculate electromagnetic form factors, a nonminimal electromagnetic interaction is introduced there.

In our papers**, we studied a dynamical model of composite particles, satisfying requirements of $\tilde{U}(12)$ invariance as well as relativistic ones. In this model the minimal electromagnetic interaction for the quarks is suggested, and electromagnetic form factors and decay vertices for baryons and bosons are obtained.

2. RELATIVISTIC EQUATION FOR MESONS [1]

We consider the composite model of elementary particles in which all the particles are regarded as bound states of three basic particles with spin 1/2. In a relativistic extension of the $SU(6)$ symmetry theory, the quarks must be described by 12-component functions $\psi_A \equiv \psi_{\alpha,a}$, where $a = 1, 2, 3$ is the $SU(3)$ index, and $\alpha = 1, 2, 3, 4$ is the Dirac spinor index. The group $SU(12)$ acting on the quark function ψ is generated by 144 matrices $\lambda_i\Gamma_r$, where λ_i are the nine generators of U(3), and Γ_r are the sixteen Dirac matrices which form $\tilde{U}(4)$. We denote the antiquark wave function by $\psi^B \equiv \psi^{\beta,b}$.

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**See Ref. [1] of Tavkhelidze, A., Higher Symmetries and Composite Models of Elementary Particles, these Proceedings.

Mesons which are bound states of the quark and antiquark are described by a mixed spinor of the second rank ψ_A^B. The question is to find an equation for $\psi_A^B(x_1, x_2)$.

In order to study the bound states of the system one could resort to the methods employed in quantum field theory, viz., to the Bethe–Salpeter equation. However, there are well-known difficulties connected with a solution of this equation in the case of strong interactions.

We will therefore start from the relativistic-invariant equation for two particles admitting solutions of the form

$$\psi_A^B(x_1, x_2) = \phi_1(x_1 - x_2)\phi_A^B(x_1 + x_2), \tag{2.1}$$

where $\phi_A^B(x_1 + x_2)$ is a mixed spinor of the second rank which describes the motion of the system as a whole, and $\phi(x_1 - x_2)$ is a scalar function describing the relative motion of particles. The simplest example of an equation invariant under a homogeneous group* $\tilde{U}(12)$ and describing the interaction of two particles is the squared Dirac equation with the factorizing potential:

$$\begin{aligned} \mathcal{D}_A^{A'}(x_1)\bar{\mathcal{D}}_{B'}^{B}(x_2)\psi_{A'}^{B'}(x_1, x_2) &= -igW(x_1 - x_2)\times \\ \times \int dx_1' dx_2' W(x_1' - x_2')\delta(x_1 + x_2 - x_1' - x_2')\psi_A^B(x_1', x_2'), \end{aligned} \tag{2.2}$$

where $\mathcal{D}(\bar{\mathcal{D}})$ is the squared Dirac operator for the particle (antiparticle)

$$\mathcal{D}_{A(B')}^{A'(B)}(x) = \left[\left(M \mp i\sum_{n=0}^{3}\gamma^n\frac{\partial}{\partial x^n}\right)\right]\left[\left(M \pm i\sum_{n=0}^{3}\gamma^n\frac{\partial}{\partial x^n}\right)\right] \tag{2.3}$$

and

$$\gamma^n\gamma^m + \gamma^m\gamma^n = 2g^{mn}, \quad g^{11} = g^{22} = g^{33} = -g^{00} = -1.$$

We require that the Fourier transform $W(q^2)$ of the scalar function $W(x)$ be real in the Euclidean space. In particular, $W(q^2)$ can be taken in the form

$$W(q^2) = \sum_N \frac{C_N}{(q^2 - N^2 - i\epsilon)^2}. \tag{2.4}$$

The operators $\mathcal{D}$ and W do not act on the spinor and unitary indices. Thus, Eq.(2.2) is invariant under $\tilde{U}(12)$ in a trivial fashion. Before including into Eq.(2.2) the symmetry breaking terms we shall study it in more detail.

Performing the Fourier transform

$$\begin{aligned} \psi_A^B(x_1, x_2) &= \int \psi_A^B(p_1, p_2)e^{-ip_1x_1 - ip_2x_2}dp_1\, dp_2 \\ W(x_1 - x_2) &= \int W(q^2)e^{-iq(x_1 - x_2)}dq \end{aligned} \tag{2.5}$$

*$\tilde{U}(12)$ acts only on the discrete indices and does not affect the variables x.

we write Eq. (2.2) in the form

$$(p_1^2 - M^2)(p_2^2 - M^2)\psi_A^B(p_1, p_2) = -ig_0\pi^4 W(q^2)\phi_A^B(p)$$
$$p = p_1 + p_2 \quad q = \tfrac{1}{2}(p_1 - p_2), \tag{2.6}$$

where

$$\phi_A^B(p) = \int W(q^2)\psi_A^B\left(\frac{p}{2} + q, \frac{p}{2} - q\right). \tag{2.7}$$

Assuming the quark mass M to be large (infinite in the limit) and taking into account only the higher terms in M, we obtain in the zero approximation

$$\begin{aligned} \psi_A^B\left(\frac{p}{2} + q, \frac{p}{2} - q\right) &= -igW(q^2)\phi_A^B(p) \\ g &= \frac{g_0\pi^4}{M^4}. \end{aligned} \tag{2.8}$$

Multiplying (2.8) by $W(q^2)$ and integrating over q we get

$$1 = -ig\int W^2(q^2)dq. \tag{2.9}$$

The function $\phi_A^B(p)$ describing the motion of the system as a whole remains undetermined. Going over to the Euclidean momenta $q_0 \to iq_4$ and taking into account (2.9) we obtain the real value for the charge

$$1 = g\int W^2(-q_E^2)dq_E, \tag{2.10}$$

q_E is the four-momentum in the Euclidean space.

In order to get equations for the function $\phi_A^B(p)$ we rewrite (2.6) as

$$\begin{aligned} \left(\frac{1}{2}p^2 + 2q^2\right)\psi_A^B\left(\frac{p}{2} + q, \frac{p}{2} - q\right) &= \frac{1}{M^2}(M^4 + p_1^2p_2^2)\psi_A^B\left(\frac{p}{2} + q, \frac{p}{2} - q\right) \\ &+ i\frac{g_0\pi^4}{M^2}W(q^2)\phi_A^B(p). \end{aligned} \tag{2.11}$$

Multiplying Eq. (2.11) by $W(q^2)$, integrating over q and using Eqs.(2.8) and (2.9) we get

$$(p^2 - m^2)\phi_A^B(p) = 0, \tag{2.12}$$

where the meson mass is given by the expression

$$m^2 = 4ig\int q^2W^2(q^2)dq = 4\frac{\int q_E^2W^2(q_E^2)dq_E}{\int W^2(-q_E^2)dq_E}. \tag{2.13}$$

Later on we use the solution of Eq.(2.12) which satisfies the supplementary condition:

$$(\gamma_0 \cdot p)_A^{A'}\phi_{A'}^B(p) + (\gamma \cdot p)_{B'}^B\phi_A^{B'}(p) = 0. \tag{2.14}$$

This condition chooses the solutions corresponding to opposite signs of the energies for the quark and antiquark. This can be easily seen if we rewrite (2.14) in the rest frame:

$$(\gamma_0)_A^{A'}\phi_{A'}^B + (\gamma_0)_{B'}^B\phi_A^{B'} = 0. \tag{2.15}$$

Since $p^2 = m^2$, we can require a simultaneous fulfilment of the Eqs. (a) or (b):

$$\begin{aligned}(\hat{p}-m)_A^{A'}\phi_{A'}^B = 0, \quad (\hat{p}+m)_{B'}^B\phi_A^{B'} = 0, \quad (a)\\ (\hat{p}+m)_A^{A'}\phi_{A'}^B = 0, \quad (\hat{p}-m)_{B'}^B\phi_A^{B'} = 0. \quad (b)\end{aligned} \tag{2:16}$$

Further we shall use Eqs.(2.16a). Note that the supplementary condition (2.16) breaks up the $\tilde{U}(12)$ invariance. Indeed, in the rest frame $\vec{p}=0$ (2.16a) reduces to (2.14) which is invariant under the group $SU(6)$.

We note that the condition (2.14) selects the mesons with a negative intrinsic parity.

Let us investigate in more detail the spinor and unitary structure of the functions ϕ_A^B. The mixed spinor of the second rank can be represented as

$$\phi_{\alpha,p}^{\beta,q} = [\phi^i + \gamma^5\phi_5^i + i\gamma^\mu\gamma^5\phi_{\mu5}^i + \gamma^\mu\phi_\mu^i + \frac{1}{2}\sigma^{\mu\nu}\phi_{\mu\nu}^i]_\alpha^\beta(\lambda_i)_p^q \tag{2.17}$$

where $i = 0\ldots 8$, $\sigma^{\mu\nu} = \frac{i}{2}(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu)$ and λ_i are Gell-Mann matrices.

Substituting Eq. (2.17) into Eqs. (2.16) we get [2]

$$\begin{aligned}p_\mu\phi_5^i = im\phi_{\mu5}^i, \quad \phi^i = 0, \quad p_\mu\phi_\nu^i - p_\nu\phi_\mu^i = im\phi_{\mu\nu}^i,\\ p_\mu\phi_{\mu5}^i = -im\phi_5^i, \qquad p^\nu\phi_{\nu\mu}^i = -im\phi_\mu^i.\end{aligned} \tag{2.18}$$

It follows from here the vector field should be transverse:

$$p_\mu\phi_\mu^i = 0$$

$$\phi_A^B = \left[\left(1+\frac{\hat{p}}{m}\right)(\gamma_5\phi_5 + \gamma_\mu\phi_\mu)\right]_A^B.$$

3. FORM FACTORS AND THE MAGNETIC MOMENTS OF MESONS

To calculate the form factors of mesons, we consider Eqs.(2.2) in a weak external electromagnetic field. For this purpose we make the usual substitution

$$i\frac{\partial}{\partial x^m} \to i\frac{\partial}{\partial x^m} + eA_m(x) \tag{3.1}$$

and write Eq. (2.2) in the form

$$\begin{aligned}\mathcal{D}_A^{A'}(x_1,A)\bar{\mathcal{D}}_{B'}^B(x_2,A)\psi_{A'}^{B'}(x_1,x_2) = -ig_0W(x_1-x_2)\times\\ \times\int dx_1'dx_2'W(x_1'-x_2')\delta(x_1+x_2-x_1'-x_2')\psi_A^B(x_1',x_2'),\end{aligned} \tag{3.2}$$

where

$$\mathcal{D}_A^{A'}(x,A) = \left[\left(M - i\gamma^n \frac{\partial}{\partial x^n} - e\hat{A}(x)\right)\left(M + i\gamma^n \frac{\partial}{\partial x^n} + e\hat{A}(x)\right)\right]_A^{A'} \tag{3.3}$$

$$\mathcal{D}_{B'}^{B}(x,A) = \left[\left(M - i\gamma^n \frac{\partial}{\partial x^n} + e\hat{A}(x)\right)\left(M + i\gamma^n \frac{\partial}{\partial x^n} + e\hat{A}(x)\right)\right]_{B'}^{B}.$$

Here e is the matrix of the electric charge which is expressed in a certain way in terms of the matrices λ.

Retaining in Eq.(3.3) the first order terms in e and making use of the expansion in the large mass of the quark M, we get an equation describing the motion of the meson in a weak electromagnetic field

$$\begin{aligned}(p^2 - m^2)\phi_A^B(p) = 2\int dk\, f(k^2) p\cdot A(k)[e_A^{A'}\phi_{A'}^B + e_{B'}^B \phi_B^{B'}(p-k)] + \\ +2\int dk\, f(k^2)[(e\hat{k}\hat{A})_A^{A'}\phi_{A'}^B(p-k) + (e\hat{A}\hat{k})_{B'}^B \phi_A^{B'}(p-k)],\end{aligned} \tag{3.4}$$

or, in the x-representation,

$$\begin{aligned}(\Box_x + m^2)\phi_A^B(x) = 2i\tilde{A}_\mu(x)\left[e_A^{A'}\frac{\partial}{\partial x_\mu}\phi_{A'}^B + e_{B'}^B \frac{\partial}{\partial x_\mu}\phi^{B'}(x)\right] + \\ +2i\left[\left(e\gamma^\mu\gamma^\nu\frac{\partial \tilde{A}_\nu}{\partial x^\mu}\right)_A^{A'}\phi_{A'}^B(x) - \left(e\gamma^\mu\gamma^\nu\frac{\partial \tilde{A}_\nu}{\partial x^\mu}\right)_{B'}^B \phi_A^{B'}(x)\right],\end{aligned} \tag{3.4a}$$

$$\tilde{A}(x) = \int \mathrm{e}^{-ikx} f(k) A(k) dk,$$

where $f(k^2)$ is determined in the following way

$$f(k^2) = \frac{\int dq\, W\left(q - \frac{k}{2}\right) W(q)}{\int dq\, W^2(q)}. \tag{3.5}$$

Before calculating the form factor of mesons we consider the case of the constant magnetic field. Using Eq.(2.16) one can see that for large components ϕ we obtain

$$\phi = a + \vec{\sigma}\cdot\vec{\varphi} \tag{3.6}$$

and for the vector field $\vec{\varphi}$ in the constant magnetic field the following equation holds

$$(p^2 - m^2)\vec{\varphi} = 2ie[\vec{H}\cdot\vec{\varphi}], \tag{3.7}$$

where e is the charge of the vector meson.

It follows from Eq. (3.7) that the magnetic moment of the vector meson is equal to e/m. We make two important remarks: (a) the expression for the magnetic moment involves not the quark mass M, but the meson mass m; (b) the magnetic moment of the meson regarded as a composite particle is twice as big as the normal magnetic moment of the vector meson with charge e and mass m. Now we pass to a calculation of the meson form factors.

Let us rewrite Eq.(3.4) in a more compact form

$$(p^2 - m^2)\phi_A^B = \int dk\, f(k^2)\left[\Gamma_A^{A'}(k,p)\phi_{A'}^B(p-k) + \Gamma_{B'}^B(p,k)\phi_A^{B'}(p-k)\right], \tag{3.8}$$

where the notations are introduced

$$\Gamma_A^{A'} = 2[p\cdot A(k)e + e\hat{k}\cdot\hat{A}]_A^{A'},$$
$$\Gamma_{B'}^B = 2[p\cdot A(k)e + e\hat{A}\cdot\hat{k}]_{B'}^B. \tag{3.9}$$

By definition the meson vertex is given by

$$\mathcal{J}(p,p-k) = 2mJ_\alpha\cdot A^\alpha \equiv \bar{\phi}_B^A(p)\Gamma_A^{A'}(p,k)\phi_{A'}^B(p-k) + \bar{\phi}_B^A\Gamma_{B'}^B(p,k)\phi_A^{B'}(p-k). \tag{3.10}$$

Substituting the spinor ϕ_B^A in the form of Eq. (2.17) and using Eq. (2.18) we get the electromagnetic vertex in the following form

$$\begin{aligned} J_\alpha = \frac{p_\alpha}{m} f(k^2)\Big\{\left(1+\frac{k^2}{8m^2}\right)(\bar{\varphi}_\mu\varphi_\mu)_F^e - \left(1+\frac{k^2}{4m^2}\right)(\bar{\varphi}_5\varphi_5)_F^e - \\ -\frac{1}{2m^2}(k^\mu k^\nu - \frac{1}{4}g^{\mu\nu}k^2)(\bar{\varphi}_\mu\varphi_\nu)_F^e\Big\} + \frac{k_\mu}{m} f(k^2)[\bar{\varphi}_\mu\varphi_\alpha - \bar{\varphi}_\alpha\varphi_\mu]_F^e + \\ +\frac{1}{m^2}\epsilon^{\alpha\beta\sigma\rho}p_\sigma k_\rho[\bar{\varphi}_\beta\varphi_5 - \bar{\varphi}_5\varphi_\beta]_D^e, \end{aligned} \tag{3.11}$$

where

$$(\bar{\varphi}\varphi)_F^e = \bar{\varphi}_{q'}^p\varphi_q^{q'}e_p^q - \bar{\varphi}_{q'}^p e_q^{q'}\varphi_p^q,$$
$$(\bar{\varphi}\varphi)_A^e = \bar{\varphi}_{q'}^p\varphi_q^{q'}e_p^q + \bar{\varphi}_{q'}^p e_q^{q'}\varphi_p^q. \tag{3.12}$$

From this expression we have

$$g_E^V = ef(k^2)\left(1+\frac{k^2}{8m^2}\right), \quad g_E^P = ef(k^2)\left(1+\frac{k^2}{4m^2}\right),$$
$$g_Q^V = \frac{2e}{m^2}f(k^2), \quad g_M^V = \frac{e}{m}f(k^2), \tag{3.13}$$

where $g_E^{V,P}$ is the electric form factor for the vector and pseudoscalar mesons respectively, g_M^V is the magnetic form factor for vector mesons, and g_Q^V is the quadrupole moment of vector mesons.

The last term in (3.11) describes the radiative decay of vector mesons. Substituting there the known matrices for pseudoscalar and vector mesons, we get

$$[\bar{\varphi}_5\varphi_\beta]^e_D = \frac{1}{3}\left[\bar{\pi}^+\rho^+ + \bar{\pi}^-\rho^- + \bar{K}^+K^+ + \bar{K}^-K^- - 2\bar{K}^0K^{*0} - 2K^0\bar{K}^{*0}\right] + \\ + \left[\frac{1}{3}\bar{\pi}^0 + \frac{1}{\sqrt{3}}\bar{\eta}^0 + \sqrt{\frac{2}{3}}\bar{\chi}^0\right]\rho_0 + \left[\frac{1}{\sqrt{3}}\bar{\pi}^0 + \frac{1}{3}\bar{\eta}^0\right]\varphi^0 + \\ + \left[\sqrt{\frac{2}{3}}\bar{\pi}^0 + \frac{\sqrt{2}}{3}\bar{\eta}^0 + \frac{2}{3}\bar{\chi}^0\right]\omega^0. \tag{3.14}$$

For the physical particles ω and φ we have

$$\omega = \sqrt{\frac{2}{3}}\omega_0 + \sqrt{\frac{1}{3}}\varphi_0, \\ \varphi = \sqrt{\frac{1}{3}}\omega_0 - \sqrt{\frac{2}{3}}\varphi_0. \tag{3.15}$$

The matrix elements for the radiative decay are given by the expression

$$M = -\frac{2e}{m} g_{VP}\epsilon^{\alpha\beta\sigma\rho}p_\sigma k_\rho A_\alpha(\bar{\varphi}_5\varphi_\beta)^e_D, \tag{3.16}$$

where the radiative decay constants are equal to

$$g_{\omega\pi^0} = 3g_{\rho^0\pi^0} = \sqrt{3}g_{\rho^0\eta^0} = 3g_{K^{*+}K^+} = 3g_{K^{*-}K^-} = 3\sqrt{3}g_{\omega\eta^0} = \frac{3\sqrt{3}}{2\sqrt{2}}g_{\varphi\eta_0} = -\frac{3}{2}g_{K^{*0}K^0}. \tag{3.17}$$

Taking into account the mass difference between the mesons only in the phase space, we get the following expression for the decay width

$$\Gamma_{V\to p+\gamma} = \alpha\frac{4}{3}m_V\left(\frac{m_V^2 - m_p^2}{2m_V^2}\right)^3 g^2_{Vp}, \tag{3.18}$$

where α is the fine structure constant, m_V and m_p are the masses of vector and pseudoscalar mesons.

Now we write down the matrix element for the decay of a heavy pseudoscalar meson χ_0 into the vector mesons:

$$M = \frac{2e}{M}g_{\chi_0 V}\epsilon^{\alpha\beta\sigma\rho}p_\sigma k_\rho A_\alpha\bar{\varphi}_\beta\varphi_5. \tag{3.19}$$

Here $g_{\chi_0 V}$ is the radiative decay constant of χ_0 meson. We carry out calculations without mixing χ_0 and η_0 mesons. We obtain

$$g_{\chi_0\rho_0} = \frac{3}{2}g_{\chi_0\omega} = \sqrt{\frac{2}{3}} \tag{3.20}$$

and

$$\Gamma_{\chi_0\to V+\gamma} = 4\alpha M_\chi\left(\frac{m_\chi^2 - m_V^2}{2m_\chi^2}\right)g^2_{\chi_0 V} \tag{3.21}$$

where m_χ is the mass of pseudoscalar χ_0 meson.

4. RELATIVISTIC EQUATION FOR BARYONS [1]

We apply the above developed method to obtain an equation describing the baryons. In the quark model the baryons are regarded as bound states of three quarks. Thus, the wave function of the baryon is a spinor of the third rank $\psi_{ABC}(x_1, x_2, x_3)$.

By analogy with the meson case we consider the relativistic invariant equation for ψ_{ABC} which admits the solution of the form

$$\psi_{ABC}(x_1, x_2, x_3) = \varphi(x_1 - x_3, x_2 - x_3)\phi_{ABC}(x_1 + x_2 + x_3), \tag{4.1}$$

where ϕ_{ABC} is the spinor of the third rank which describes the motion of the centre of mass of the bound system of three quarks, i.e., the baryon as a whole, φ stands for some scalar function.

To get an equation describing the motion of baryons in a weak external electromagnetic field we shall start from the squared Dirac equation

$$\mathcal{D}_A(x_1)\mathcal{D}_B(x_2)\mathcal{D}_C(x_3)\psi_{ABC}(x_1, x_2, x_3) = g_0 W(x_1, x_2, x_3) \times$$
$$\times \int dx_1' dx_2' dx_3' W(x_1', x_2', x_3')\delta(x_1 + x_2 + x_3 - x_1' - x_2' - x_3')\psi_{ABC}(x_1', x_2', x_3'), \tag{4.2}$$

where the operators $\mathcal{D}$ are given by the expression (3. 3), $W(x_1, x_2, x_3)$ is the scalar function which satisfies the conditions

$$W(x_1, x_2, x_3) = W(x_1 + a, x_2 + a, x_3 + a),$$
$$W(x_1, x_2, x_3) = W(-x_1, -x_2, -x_3). \tag{4.3}$$

The Fourier transform $W(q_1, q_2, q_3)$ of the scalar function W may be, for example, taken in the form

$$W(q_1, q_2, q_3) = \sum_N \frac{C_N}{[N^2 - (q_1 - q_2)^2 - i\epsilon][N^2 - (q_2 - q_3)^2]} \times \frac{1}{N^2 - (q_1 - q_3)^2 - i\epsilon}. \tag{4.4}$$

To get the equation for the function

$$\phi_{ABC}(x_1 + x_2 + x_3) = \int W(x_1', x_2', x_3')\psi_{ABC}(x_1', x_2', x_3') \times$$
$$\times \delta(x_1 + x_2 + x_3 - x_1' - x_2' - x_3') dx_1' dx_2' dx_3' \tag{4.5}$$

we use again, by analogy with the meson case, the expansion in the large mass of the quark M and retain the terms of the first order in the charge e. As a result, for the Fourier transform of the function (4. 5) we get the following equation

$$(p^2 - m_N^2)\phi_{ABC}(p^2) = 2\int dk\, f(k^2) A \cdot p[e_A + e_B + e_C]\phi_{ABC}(p - k) \times$$
$$\times 3\int dk\, f(k^2)[(e\hat{k}\hat{A})_A + (e\hat{k}\hat{A})_B + (e\hat{k}\hat{A})_C]\phi_{ABC}(p - k), \tag{4.6}$$

where the nucleon mass m_N is determined from the equation similar to (2.13), while the function $f(k^2)$ is given by

$$f(k^2) = \frac{\int W(p_1,p_2,p_3)W(p_1+k,p_2,p_3)\delta(p_1+p_2+p_3)dp_1\,dp_2\,dp_3}{\int W^2(p_1,p_2,p_3)\delta(p_1+p_2+p_3)dp_1\,dp_2\,dp_3}. \qquad (4.7)$$

From this, in particular, it is seen that* $F(0) = 1$.

When the electromagnetic field is absent Eq. (4.2) is invariant under $\tilde{U}(12)$ as the operators $\mathcal{D}$ and W have no spin and unitary structure; the free equation

$$(p^2 - m^2)\phi_{ABC} = 0 \qquad (4.8)$$

is also invariant under $\tilde{U}(12)$. In order not to mix the solutions with positive and negative energies in the free case, we use a supplementary condition

$$(\hat{p})_A^{A'}\phi_{A'BC} = (\hat{p})_B^{B'}\phi_{A'B'C} = (\hat{p})_C^{C'}\phi_{ABC'}. \qquad (4.9)$$

We require that ϕ_{ABC} satisfy simultaneously the following equations

$$(\hat{p}-m)_A\phi_{ABC} = (\hat{p}-m)_B\phi_{ABC} = (\hat{p}-m)_C\phi_{ABC} = 0. \qquad (4.10)$$

Conditions (4.9) and (4.10) break the invariance under the group $\tilde{U}(12)$, conserving, at the same time, the invariance under $SU(6)$.

Consider the solution (4.8)–(4.10) corresponding to the symmetrical spinor of the third rank. The symmetrical spinor ϕ_{ABC} is a relativistic generalization of 56-plet in the non-relativistic scheme $SU(6)$.

The symmetrical spinor ϕ_{ABC} may be represented as [2]

$$\begin{aligned}\phi_{ABC} = \phi_{(\alpha p)(\beta q)(\gamma r)} &= \sqrt{\frac{1}{8}}D_{\alpha\beta\gamma}d_{pqr} + \\ &+ \frac{1}{6\sqrt{2}}\left[N_{[\alpha\beta]\gamma}\epsilon_{pqs}B_r^s + N_{[\beta\gamma]\alpha}\epsilon_{qrs}B_p^s + N_{[\gamma\alpha]\beta}\epsilon_{rps}B_q^s\right], \qquad (4.11)\end{aligned}$$

where $D_{\alpha\beta\gamma}$ is the symmetrical spinor of the third rank, $N_{[\alpha\beta]\gamma}$ is the spinor antisymmetrical with respect to the indices α, β, d_{pqr} stands for the unitary decuplet, B_q^p is the unitary octet.

Using relations (2.17) one can obtain [2]

$$D_{\alpha\beta\gamma} = \psi_{\alpha\mu}(\gamma_\mu C)_{\beta\gamma} - \frac{i}{2m}(p_\mu\psi_\nu - p_\nu\psi_\mu)_\alpha(\sigma^{\mu\nu}C)_{\beta\gamma}, \qquad (4.12a)$$

*To get form factors of mesons and baryons (3.8–4.6) we use the equation which contains the squared Dirac operators $\hat{\partial}^2$, and the factorizable potentials. As Bogolubov has shown [3], these results remain unchanged, if we use nonsquared Dirac operators for quarks and describe bound states with a Bethe–Salpeter-type equation. For example Bogolubov's equation for bosons has the form

$$\left\{(\hat{\partial}_1 - M)(\hat{\partial}_2 + M) - \gamma_1^{(5)}\gamma_2^{(5)}W\right\}\psi = 0,$$

where

$$W(x_1,x_2) = M^2 - u(x_1 - x_2).$$

$$N_{[\alpha\beta]\gamma} = \frac{[(\hat{p}+m)\gamma_s C]_{\alpha\beta}}{m}\psi_\gamma, \tag{4.12b}$$

where C is determined by $(\gamma_\mu C)_{\alpha\beta} = (\gamma_\mu C)_{\beta\alpha}$, $C^T = -C$.

The spinors ψ and ψ_μ satisfy the equations

$$(\hat{p}-m)\psi_\mu = 0, \quad \gamma^\mu \psi_\mu = 0, \tag{4.13a}$$

$$(\hat{p}-m)\psi = 0, \quad p^\mu \psi_\mu = 0, \tag{4.13b}$$

so:

$$D_{\alpha\beta\gamma} = \psi_{\mu\alpha}\left[\left(1+\frac{\hat{p}}{m}\right)\gamma_\mu C\right]_{\beta\gamma}.$$

Consider the baryon in a constant magnetic field. Retaining only the large components of the spinor ϕ_{ABC} we get from (4.6)

$$(p^2 - m^2)\phi_{ABC} = 3[(e\vec{\sigma})_A + (e\vec{\sigma})_B + (e\vec{\sigma})_C]\vec{H}\phi_{ABC}. \tag{4.14}$$

Here the spinor indices run from one to two. It can be seen from (4.14) that the effective magnetic moment of the quark with charge e in the baryon is $3e/2m$ and the operator of the baryon magnetic moment is

$$\vec{\mu} = \frac{3}{2m}[(e\vec{\sigma})_1 + (e\vec{\sigma})_2 + (e\vec{\sigma})_3]. \tag{4.15}$$

Averaging (4.14) over the functions corresponding to the particles with spins 3/2 and 1/2 we get the well-known relations among the magnetic moments following from the $SU(6)$ symmetry [4].

It is rather interesting that the magnetic moment of the proton calculated by Eq.(4.14) turns out to be equal to three nuclear magnetons. Thus, just as in the meson case, the magnetic moment in the composite model is determined by the mass of the bound state, and the composite particle possesses an anomalous magnetic moment.

Let us now study the electromagnetic form factors of baryons. We consider the vertex

$$3\bar{\phi}^{ABC}\Gamma_A^{A'}\phi_{A'BC} = 2mJ_\alpha A^\alpha, \tag{4.16}$$

where

$$\Gamma_A^{A'}(k) = \left[2e_p^{p'}A_\mu \cdot p^\mu + \frac{3}{2}(\sigma^{\mu\nu})_\alpha^{\alpha'} e_p^{p'} F_{\mu\nu}(k)\right] f(k^2)$$

is the matrix of the electric charge.

Substituting (4.11), (4.12) into (4.16) we obtain

$$\begin{aligned}
J_\alpha &= 3\left\{-\frac{p_\alpha}{m}\left(1+\frac{k^2}{4m^2}\right)(\bar{\psi}_\mu\psi^\mu) + \frac{p_\alpha}{m^3}\left(k^\mu k^\nu - \frac{1}{4}g^{\mu\nu}k^2\right)\bar{\psi}_\mu\psi_\nu + \right.\\
&+ \left.\frac{3kp}{2m}(\bar{\psi}_\mu\psi_\alpha - \bar{\psi}_\alpha\psi_\mu)\right\} d^{pqr}e_p^{p'}d_{p'qr}f(k^2) \times \\
&\times \left\{\left(1+\frac{k^2}{4m^2}\right)\frac{p_\alpha}{m}(\bar{\psi}\psi)_F^e - \frac{1}{4m^2}(\bar{\psi}r_\alpha\psi)_{3D+2F}^e\right\} f(k^2) + \\
&+ \frac{3}{m^2}\epsilon^{\alpha\beta\sigma\rho}p_\sigma k_\rho\left\{\bar{\psi}_\beta\psi d^{pqr}e_p^{p'}\epsilon_{p'qs}B_r^s - (\bar{\psi}\psi_\beta)\epsilon^{pqs}B_s^r e_p^{p'}d_{p'qr}\right\} f(k^2)
\end{aligned} \tag{4.17}$$

$$r_\alpha = 2\epsilon^{\alpha\sigma\rho\lambda} p_\sigma k_\rho \gamma_\lambda \gamma_5.$$

Here d_{pqr} is the wave function of the decuplet, B^s_r is the wave function of the octet, ψ_μ is the wave function of particles with spin 3/2, and ψ is the wave function for particles with spin 1/2. From (4.17) we have

$$\begin{aligned}
G_E^{3/2} &= eF(k^2)\left(1+\frac{k^2}{4m^2}\right), \\
G_E^{1/2} &= eF(k^2)\left(1+\frac{k^2}{2m^2}\right), \\
G_M^{3/2} &= \frac{3e}{2m}F(k^2), \\
G_M^{1/2} &= \frac{e}{2m}F(k^2)\mu; \quad \mu_p = 3 \quad \mu_n = -2 \quad \mu_{\Sigma^-} = -1 \\
G_Q^{2/2} &= \frac{e}{m^3},
\end{aligned} \tag{4.18}$$

where $G_E^{3/2,1/2}$ are the electric form factors of baryons with spins 3/2 and 1/2, respectively $G_M^{3/2,1/2}$ are the magnetic form factors, $G_Q^{3/2}$ is the quadrupole moment.

The last term describes the photoproduction and decay of resonances. The matrix element for the radiative decay is given by the expression

$$M = \frac{6e}{m} g_{d\to b+\gamma} \epsilon^{\alpha\beta\sigma\rho} p_\sigma k_\rho A_\alpha \bar{\psi}\psi_\beta. \tag{4.19}$$

For the constants g_{db} we have [5]

$$g_{\Delta^+ p} = g_{\Delta^0 n} = g_{\Xi^0\Xi^0} = g_{\Sigma^+\Sigma^+} = -\frac{2}{\sqrt{3}} g_{\Sigma^0\Lambda} = 2g_{\Sigma^0\Sigma^0} = 1. \tag{4.20}$$

Taking into account the mass difference only in the phase space, we get for the decay width of resonances

$$\Gamma_{d\to b+\gamma} = 3\alpha\frac{m_d^2}{m_b}\left(\frac{m_d^2+m_b^2}{2m_d^2}\right)^3\left(1+\frac{m_b}{m_d}\right)^2, \tag{4.21}$$

where m_d is the mass of the baryon from the decuplet, and m_b is the mass of the baryon from the octet. We have seen that the interaction of the composite particle with an external electromagnetic field is nonlocal.

Note that if we apply these results to the examination of vertices in quantum electrodynamics we have to restrict ourselves to the first order of the perturbation theory, in order not to deal with difficulties connected with violation of unitarity and causality due to the nonlocal character of the interaction.

Now we discuss in more detail the symmetry properties of the wave functions of baryons. The equation which describes the baryons admits a solution of the form

$$\psi_{ABC}(x,y,z) = \varphi(x,y,z)\phi_{ABC}(x+y+z), \tag{4.22}$$

where φ is a scalar function which is symmetric with respect to the variables x, y, z.

In studying the form factors we have used the wave function which is symmetric with respect to the permutation of indices A, B, C. So we choose the completely symmetric wave function ψ_{ABC} to describe the baryon state.

However, if we consider the quarks to be Dirac particles which can be also in free states, we must require that the wave functions of baryons be antisymmetric with respect to the permutation of all quantum numbers of true quarks. Here we meet a contradiction. Choosing the completely symmetric wave function for the baryons we get good agreement between the theoretical and experimental results, although such a choice contradicts the Pauli principle. In order to avoid this contradiction we assign a new quantum number to the quark*. We assume that, besides the spin and unitary index, the quark is characterized by the quantum number a and the quark wave function will be denoted by $\psi_{\underline{ABC}}(x, y, z) = \psi_{ABC;abc}(x, y, z)$ where a runs from one to three. For the baryon wave function we have

$$\psi_{\underline{ABC}}(x, y, z) = \psi_{ABC,abc}(x, y, z)$$

We determined that the equation which describes the baryon allows a solution of the form

$$\psi_{\underline{ABC}}(x, y, z) = \frac{1}{\sqrt{6}}\epsilon_{abc}\varphi(x, y, z)\psi_{ABC}(x, y, z), \tag{4.23}$$

where ϵ_{abc} is the totally antisymmetric tensor. The presence of the tensor ϵ_{abc} guarantees the antisymmetric property of the baryon functions, if the function $\psi_{ABC}(x, y, z)$ is completely symmetric.

The relativistic invariant equation which allows the solution of the form (4.23) will be obtained by a strict generalization of Eq. (4.2). It has the form

$$\mathcal{D}_{\underline{A}}^{\underline{A}'}\mathcal{D}_{\underline{B}}^{\underline{B}'}\mathcal{D}_{\underline{C}}^{\underline{C}'}\psi_{\underline{A}'\underline{B}'\underline{C}'}(x, y, z) = \tfrac{1}{6}g\epsilon_{abc}W(x, y, z)\,\times$$
$$\times \int dx'dy'dz'W(x', y', z')\delta(x + y + z - x' - y' - z')\epsilon^{a'b'c'}\psi_{ABC,a'b'c'}(x', y', z'), \tag{4.24}$$

where D is the squared Dirac operator. In order to describe the baryons in an electromagnetic field, we must make a usual substitution

$$i\hat{\partial}_x \to i\hat{\partial}_x - e\hat{A}(x), \tag{4.25}$$

where e is the charge operator. We suppose that the charge operator acts not only on the unitary index but it acts also on the additional quantum number. Such a generalization of the charge operator leads to an integer value for the quark charge. We want to emphasize that the prediction of Eq.(4.2) concerning the form factors remains unchanged if we treat three triplets on the same footing.

We define the charge operator in the following form

$$e_{\underline{A}}^{\underline{A}'} = e_A^{A'} + e_a^{a'}. \tag{4.26}$$

The operator $e_A^{A'}$ acts on the unitary index and has the form

$$e_A^{A'} = \begin{pmatrix} \frac{2}{3} & 0 & 0 \\ 0 & -\frac{1}{3} & 0 \\ 0 & 0 & -\frac{2}{3} \end{pmatrix}. \tag{4.27}$$

*This possibility is also discussed in the recent paper by Nambu [4].

The operator $e_a^{a'}$ acts on the additional quantum numbers and is of the form

$$e_a^{a'} = \begin{pmatrix} \frac{1}{3} & 0 & 0 \\ 0 & \frac{1}{3} & 0 \\ 0 & 0 & -\frac{2}{3} \end{pmatrix}. \tag{4.28}$$

Then the charge of the quark is integer.

$$\begin{array}{c|ccc} {}^{a}_{A} & 1 & 2 & 3 \\ \hline 1 & 1 & 1 & 0 \\ 2 & 0 & 0 & -1 \\ 3 & 0 & 0 & -1 \end{array} \tag{4.29}$$

Taking into account that the operator $e_a^{a'}$ is diagonal and Sp $e_a^{a'} = 0$ we get

$$\epsilon^{abc} e_a^{a'} \epsilon_{a'bc} = 0. \tag{4.30}$$

Therefore, we have the identity

$$e_A^{A'} = \frac{1}{6} \epsilon^{abc} \left(e_A^{A'} + e_a^{a'} \right) \epsilon_{a'bc}. \tag{4.31}$$

Let us consider Eq.(4.26) where the charge operator e has the form $e_{\underline{A}}^{\underline{A}'} = e_A^{A'} + e_a^{a'}$. Retaining in this equation the first order terms in e and making use of the expansion in the large mass of the quark M, we get an equation describing the motion of the baryon in a weak electromagnetic field

$$\begin{aligned} (p^2 - m^2)\phi_{\underline{ABC}}(p) &= \int dk\, f(k) \left[\Gamma_{\underline{A}}^{\underline{A}'} + \Gamma_{\underline{B}}^{\underline{B}'} + \Gamma_{\underline{C}}^{\underline{C}'} \right] \phi_{\underline{A}'\underline{B}'\underline{C}'}(p - k) \\ \Gamma_{\underline{A}}^{\underline{A}'} &= [2A \cdot pe + 3(e\hat{k} \cdot \hat{A})]_{\underline{A}}^{\underline{A}'}. \end{aligned} \tag{4.32}$$

For the nonperturbed solution we have

$$\phi_{\underline{ABC}}^{(p)} = \frac{1}{\sqrt{6}} \epsilon_{abc} \phi_{ABC}(p). \tag{4.33}$$

Substituting (4.33) into (4.32) after averaging over the functions $\frac{1}{\sqrt{6}}\epsilon_{abc}$ and taking into account (4.32) we arrive again to Eq.(1.2) which was our goal.

Assigning a new quantum number, we may construct 3 types of mesons $\psi_{A,1}^{B,1}$, $\psi_{A,2}^{B,2}$, $\psi_{A,3}^{B,3}$. The charges of these mesons coincide with the charge of the known mesons. The mesons are constructed by the triplet 1 with charge (100), the mesons $\psi_{A,2}^{B,2}$ — for the triplet 2 with charge (100) and $\psi_{A,3}^{B,3}$ are constructed by the triplet 3 with charge (0 -1 -1).

In order that the meson form factors remained unchanged, it is sufficient that the zero approximation solution take the form

$$\psi_{A,a}^{B,b} = \frac{1}{\sqrt{3}} \delta_b^a \psi_A^B. \tag{4.34}$$

Such a solution selects the mesons in which the states ψ_1^1, ψ_2^2, ψ_3^3 appear with equal weights.

Now I want to discuss briefly a possible test of the hypothesis that the mesons are constructed with three triplets.

From the expression for the electromagnetic meson form factors it is easy to see that assigning the new quantum number we change only the radiative decay vertex.

Indeed, taking the charge operator in the form $\hat{e} \to \hat{e} + e_a$ we get

$$\begin{aligned} [\bar{\varphi}_5 \varphi_\beta]_F^e &\to [\bar{\varphi}_5 \varphi_\beta]_F^e \\ [\bar{\varphi}_5 \varphi_\beta]_D^e &\to [\bar{\varphi}_5 \varphi_\beta]_D^e + 2e_a \bar{\varphi}_5 \varphi_\beta, \end{aligned} \tag{4.35}$$

where $e_a = 1/3$ for the mesons ψ_1^1, ψ_2^2, and $-2/3$ for the mesons ψ_3^3.

The results of calculations for the radiative decay constant are given in the Table.

Table. RADIATIVE DECAY CONSTANTS

Decay	Quark models	ψ_1^1, ψ_2^2	ψ_3^3
$\rho_0 \to \pi_0 \gamma$	$1/3$	1	-1
$k^{*\pm} \to k^{\pm}\gamma$	$1/3$	1	-1
$k^{*0} \to k^0 \gamma$	$-2/3$	0	-2
$\omega \to \pi^0 \gamma$	1	1	2
$\omega \to \eta^0 \gamma$	$\frac{1}{3\sqrt{3}}$	$\frac{1}{\sqrt{3}}$	$-\frac{1}{\sqrt{3}}$
$\varphi \to \eta_0 \gamma$	$\frac{2}{3}\sqrt{\frac{2}{3}}$	0	$2\sqrt{\frac{2}{3}}$
$\chi_0 \to \rho_0 \gamma$	$-\sqrt{\frac{2}{3}}$	$-\sqrt{\frac{2}{3}}$	$-\sqrt{\frac{2}{3}}$
$\chi_0 \to \omega\gamma$	$-\frac{2}{3}\sqrt{\frac{2}{3}}$	0	$-2\sqrt{\frac{2}{3}}$

REFERENCES

1. Delbourgo, R., Salam, A. and Strathdee, J., Proc. Roy. Soc. A. V. 287.

2. Bogolubov, N. et al., JINR preprint D-2075, Dubna (1965); JINR preprint P-2141, Dubna, (1965).

3. Bogolubov, P., JINR preprint, Dubna (1965).

4. Nambu, Y., preprint (1965).

5. Beg, M., Lee, B. and Pais, A., Phys. Rev. Lett., 13 (1964) 514.

SHORT ESSAY ON THE LIFE AND SCIENTIFIC ACTIVITY OF ACADEMICIAN A.N. TAVKHELIDZE

Albert Nikiforovich Tavkhelidze was born on December 16, 1930 in Tbilisi. He grew up in a friendly hospitable family of rich traditions; very musical, revering cultured and educated people.

In 1948, A.N. Tavkhelidze graduated from Tbilisi high school No.8 for boys, and in 1953 from Tbilisi State University in «theoretical physics». The thorough preparation acquired in the university together with the recommendations of academicians I.N. Vekua and N.I. Muskhelishvili made it possible for him to undertake a postgraduate course at the V.A. Steklov mathematical institute of the USSR Academy of Sciences (MIAS). His scientific supervisor was Academician N.N. Bogoliubov. In 1957, A.N. Tavkhelidze presented a thesis to the MIAS Scientific Council and successfully obtained his scientific degree of Candidate of Physics and Mathematics*.

In 1956, A.N. Tavkhelidze received an invitation for work from N.N. Bogoliubov and A.A. Logunov, and his scientific activities started at the Laboratory of Theoretical Physics of the Joint Institute for Nuclear Research (LTP, JINR), the international physics centre that had just been created in Dubna. The elevated scientific, extremely helpful and friendly atmosphere that reigned in JINR encouraged creative scientific research.

A.N. Tavkhelidze worked in Dubna for the period from 1956 to 1970, he started as scientific researcher and became Deputy Director of the Laboratory of Theoretical Physics. In 1963, A.N. Tavkhelidze presented his dissertation to the JINR LTP Scientific Council and received a degree of Doctor of Physics and Mathematics. In 1965, he was conferred the title of Professor. Together with academicians N.N. Bogoliubov and A.A. Logunov he devoted much time to preparation of the younger scientific generation, and attracted the most talented students and postgraduate students to the Laboratory of Theoretical Physics.

Significant credit should be given to A.N. Tavkhelidze for organizing and holding in Dubna and in other places a whole series of symposia, schools, conferences, etc. Especially notable are the informal seminars held regularly

*Ph.D. in Western Countries.

in 1966–1971 jointly by JINR and CERN (the European Centre for Nuclear Research in Geneva). The purpose of these encounters was the discussion of the most prospective lines of research in high energy physics. The directors of nearly all world nuclear centres participated in the work of one such seminar, that took place in Tbilisi in 1969.

During his work at LTP, A.N. Tavkhelidze actively participated in the scientific and organizational work of other physics institutions.

In 1965–1970, A.N. Tavkhelidze, on invitation of Academician A.A. Logunov, took part in organizing a sector of theoretical physics at the Institute of High Energy Physics (Protvino) and was its first supervisor. In 1967, the joint efforts of N.N. Bogoliubov and A.N. Tavkhelidze resulted in the establishment in Kiev of the Institute of Theoretical Physics (presently the N.N. Bogoliubov ITP), where A.N. Tavkhelidze was Head of the Department of Elementary Particle Physics (1967–1971).

In 1967, in close collaboration with academicians N.N. Bogoliubov and M.A. Markov, he succeeds in convincing the Government to adopt a decision to issue the USSR AS journal «Theoretical and Mathematical Physics». Till 1991, A.N. Tavkhelidze was Deputy Editor-in-Chief of this journal.

In 1970, A.N. Tavkhelidze was appointed by the Presidium of the USSR Academy of Sciences director of the newly created Institute of Nuclear Research (Moscow), and entrusted to develop the structure and to form the scientific subject-matter of this centre. Discussions with prominent scientists-experts together with decisive support by Academician M.A. Markov resulted in two main lines of research being established in the INR, USSR AS: particle and nuclear physics, and neutrino astrophysics. Construction was planned of base nuclear-physics experimental installations of the Institute: the Moscow meson factory (in Troitsk) and neutrino observatories with appropriate neutrino telescopes, underground near the Elbru (Baksan Neutron Observatory) and underwater in lake Baikal. Actually, the subject-matter of the Institute represented a sole new line of research – particles and cosmology.

In 1986, when A.N. Tavkhelidze was elected President of the Georgian Academy of Sciences, all preliminary work was nearly completed at the Institute, and a broad international collaboration was initiated with scientific centres of Italy, the USA and other countries; the first experiments were started. Theoretical and experimental studies performed by physicists of this Institute were already well known to the broad scientific community. At the Institute of Nuclear Research, A.N. Tavkhelidze still continues to work fruitfully as Head of the Department of Theoretical Physics and scientific leader of INR.

Starting from 1969, once every two years, mainly on the basis of INR, RAS and the Georgian AS, A.N. Tavkhelidze holds international conferences devoted to quark physics.

In 1970–1986, A.N. Tavkhelidze is professor of the M.V. Lomonosov Moscow State University, which doubtless played an important role in forming of the well known in the scientific world Department of Theoretical Physics of INR, RAS.

During his work in Moscow the ties between A.N. Tavkhelidze and Tbilisi State University and the Georgian Academy of Sciences strengthened. In 1971, with the support of Academician N.I. Muskhelishvili, a Department of Theoretical Physics was organized at the A.M. Razmadze Mathematical Institute, the staff of which was entirely made up of young scientists trained in Dubna. A.N. Tavkhelidze became Head of this department.

In 1980, on the basis of the problem laboratory of high energy physics of the physical faculty of Tbilisi State University (TSU), the staff of which consisted mainly of physicists that grew up in Dubna and that had scientific connections with it, the TSU Institute of High Energy Physics was created. A.N. Tavkhelidze entrusted to be scientific leader of the Institute.

The contribution of Georgian scientists to the development of high energy physics was highly appraised, and in 1976 with the support of the Georgian government Tbilisi hosted the XVIII Rochester Conference on high energy physics, in which nearly 1500 physicists took part.

In 1967, A.N. Tavkhelidze was elected corresponding member and in 1974 full member of the Georgian Academy of Sciences.

In 1986, A.N. Tavkhelidze was elected President of the Georgian Academy of Sciences on recommendation of the Georgian Government and with support of the USSR Academy of Sciences. In 1993 and 1998, the General assembly of the Georgian Academy of Sciences again confirmed his authority as President. The contribution of the Academy of Sciences to the scientific and intellectual life of Georgia was duly appraised. In June 1999, the Georgian parliament adopted the Law on the Academy of Sciences of Georgia submitted by the country's president. The Law establishes the Status of the Georgian Academy of Sciences, determines its tasks and the guaranties of its legal, property, organizational and financial activity.

In 1986, A.N. Tavkhelidze becomes Editor-in-Chief of the journal «Communications of the Georgian Academy of Sciences», which at present is published both in the Georgian and English languages.

Since 1995, he is Director of the Institute of High Energy Physics of the I.A. Javakhishvili Tbilisi State University. The knowledge and experience accumulated at the institute made it possible to create an Internet network within the Georgian Academy of Sciences and other Georgian state institutions of higher education.

A.N. Tavkhelidze is author of over two hundred scientific publications, which are characterized by a high quotation index. Many of his co-authors were beginning scientific researchers, and today they are prominent scientists, well known in the world, organizers of science.

For his outstanding contribution to science A.N. Tavkhelidze was elected corresponding member of the USSR Academy of Sciences in 1984, and in 1990 full member (academician) of the USSR AS (Russian Academy of Sciences since 1991).

A.N. Tavkhelidze is the USSR State prize winner (1973) for the joint research on «Photoproduction of π mesons on nucleons». The joint series of investigations entitled «New quantum number – colour and establishment of regularities in the quark structure of elementary particles and atomic nuclei» won the Lenin prize in 1988. In 1998, A.N. Tavkhelidze, together with staff members of the Institute of Nuclear Research, was awarded State prize of the Russian Federation in science for «creation of the Baksan neutrino observatory and research in neutrino astrophysics, elementary particle and cosmic ray physics».

In 1987, the discovery «Matveev–Muradyan–Tavkhelidze rules for quark counting» was registered in the USSR State register for discoveries.

In 1996, A.N. Tavkhelidze was awarded the N.N. Bogoliubov prize of the Ukrainian National Academy of Sciences. In 1998, the International Association of Academies of Sciences awarded a Gold medal to A.N. Tavkhelidze, taking into account his significant contribution to the strengthening of international scientific collaboration. For his active participation in the work of the World Federation of Scientists, and in connection with celebration of the 2000th Christmas, Pope John Paul II presented A.N. Tavkhelidze with a memorial badge.

In 1987–1990, A.N. Tavkhelidze was Deputy of the Supreme Soviet of the Georgian SSR and member of the Presidium of the Supreme Soviet of the Georgian SSR. In 1989, he was elected the USSR People's Deputy.

A.N. Tavkhelidze has a number of State decorations of the USSR and of the Russian Federation. He is a member of several foreign academies, he participates in the Pugwash movement of scientists for peace.

In his autobiography Albert Nikiforovich himself characterizes his path in science: «I developed into a physicist in the school of N.N. Bogoliubov, my mentor and teacher. During my long path of scientific and science-organizing activity I collaborated closely and associated with outstanding scientists, statesmen and administrators of high stature. Most of them were unique personalities, individuals with enormous life experience; encounters and contacts with them were extremely impressive and greatly influenced the formation of my own personality».

A.N. Tavkhelidze and his wife Maya Meunargia have a daughter Nato and son Noshrevan, as well as grandchildren Maiko and Nika...

Everyone who knows Albert Nikiforovich well always notes such qualities as his devotion to the ideals of science, his enormous will-power, his remarkable capacity for work, and his ability to rally people for achieving a set goal, his dependability in friendship and his kindness.

WORKS OF ACADEMICIAN A.N.TAVKHELIDZE REFLECTING THE MAIN LINES OF HIS SCIENTIFIC ACTIVITY
(with brief commentaries)

1. Dispersion Relations (DR) and Approximate Equations in Quantum Field Theory (QFT)

By generalizing Bogoliubov's DR method for inelastic processes and processes involving a variable number of particles in QFT, A. Tavkhelidze, together with A. Logunov, first obtained DR for the amplitudes of π-meson production on nucleons. On the basis of DR data, singular integral equations of the N. Muskhelishvili type were obtained for partial photoproduction amplitudes in the two-particle unitarity approximation (together with A. Logunov and L. Soloviev). The meson–nucleon scattering amplitude is the kernel of these equations, and the non-uniform part represents the photoproduction amplitude in the one-nucleon approximation. These results were confirmed experimentally.

On the role of bound states in the photoproduction processes // Dokl. Acad. Nauk. 1957. V.112. No.1. P.45–47. Bibl.: 2.
Co-authors: A.A.Logunov, B.M.Stepanov.

Dispersion relations for photoproduction reactions of π-mesons on nucleons // JETF. 1957. V.32. No.6. P.1393-1403. Bibl.: 5.
Co-author: A.A.Logunov.

Dispersion relations for meson-nucleon scattering processes in the static nucleon approximation // Bull. Georgian Acad. Sci. 1957. V.18. No.1. P.19–24.
Co-author: A.A.Logunov.

Photoproduction processes and dispersion relations // Nucl. Phys. 1957. V.4. P.427–452. Bibl.: 9.
Co-authors: A.A.Logunov, L.D.Solovyev.

Approximate equations for the amplitude of photon scattering on nucleons // Dokl. Acad. Nauk. 1958. V.119. No.4. P.690–693. Bibl.: 5.
Co-author: V.K.Fedianin.

The analytical properties of the amplitude of a process involving a variable number of particles // Dokl. Acad. Nauk. 1958. V.120. No.4. P.739–742. Bibl.: 2.
Co-author: A.A.Logunov.

Some problems encountered in the theory of the dispersion relations // Nucl. Phys. 1958. V.8. P.374–393. Bibl.: 8.
Co-author: A.A.Logunov.

On the dispersion relations for the reactions with the variable particle number // Zeitschrift für Naturforschung. 1958. V.13A. No.8. P.642–644. Bibl.: 3.
Co-authors: A.A.Logunov, N.A.Chernikov.

Generalized dispersion relations // Nuovo Cimento. 1958. V.10. No.6. P.943–952. Bibl.: 6.
Co-author: A.A.Logunov.

On the theory of dispersion relations // Nuovo Cimento. 1958. V.10. No.6. P.953–964. Bibl.: 6.
Co-authors: S.M.Bilenkij, A.A.Logunov.

On the renormalization group in the problems with fixed source // Nauchn. Dokl. Vys. Shk. 1958. V.2. P.169–172.

Problems of the theory of dispersion relations. JINR preprint P-143, Dubna, 1958. 30 p. Bibl.: 8.
Co-author: A.A.Logunov.

On the question of the inverse dispersion relations // Bull. Georgian Acad. Sci. 1959. V.23. No.2. P.149–156. Bibl.: 5.
Co-author: M.A.Mestvirishvili.

The spectral properties of Green's functions in a meson field model with a fixed source // Dokl. Akad. Nauk. 1959. V.129. No.4. P.769–772. Bibl.: 7.
Co-authors: I.T.Todorov, N.A.Chernikov.

Majoration of Feynman diagrams // Dokl. Akad. Nauk. 1960. V.135. No.4. P.801–804. Bibl.: 5.
Co-authors: A.A.Logunov, I.T.Todorov, N.A.Chernikov.

Application of the N.I.Muskhelishvili methods for the solution of singular integral equations in quantum field theory // Problems of Continuum Mechanics. M., 1961. P.45–59. Bibl.: 8.
Co-authors: N.N.Bogolyubov, B.V.Medvedev.

The asymptotic behaviour of the scattering amplitudes and the renormalization group method // Phys. Lett. 1962. V.2. No.3. P.150–152. Bibl.: 8.
Co-authors: B.A.Arbuzov, A.A.Logunov, R.N.Faustov.

Regge poles and perturbation theory I // Phys. Lett. 1962. V.2. No.7. P.305–306. Bibl.: 2.
Co-authors: B.A.Arbuzov, A.A.Logunov, R.N.Faustov, A.T.Filippov.

Regge poles and perturbation theory II // Phys. Lett. 1963. V.4. No.5. P.272–273. Bibl.: 6.
Co-authors: B.A.Arbuzov, B.M.Barbashov, A.A.Logunov, Nguen van Hieu, R.N.Faustov, A.T.Filippov.

The Regge poles and Bethe–Salpeter equations // Dokl. Akad. Nauk. 1963. V.150. No.4. P.764–766. Bibl.: 4.
Co-authors: B.A.Arbuzov, A.A.Logunov, R.N.Faustov.

Regge poles in quantum electrodynamics // Nucl. Phys. 1963. V.44. P.275–279. Bibl.: 4.
Co-authors: A.A.Logunov, Nguen van Hieu, O.A.Khrustalev.

Regge poles and perturbation theory // Nucl. Phys. 1963. V.49. P.170–176. Bibl.: 7.
Co-authors: A.A.Logunov, Nguen van Hieu, O.A.Khrustalev.

On an investigation of the analytic properties of the scattering amplitudes in the non-relativistic three-body problem II // JINR preprint E-1659, Dubna, 1964. 10 p. Bibl.: 5.

Quasi-potential character of the scattering amplitude // JINR preprint D-1191, Dubna, 1963. 9 p. Bibl.: 6.
Co-authors: A.A.Logunov, I.T.Todorov, O.A.Khrustalev.

Lectures on quasipotential method in field theory // Proc. Summer School in Theoretical Physics (Bangalore, 1963). Bombay, 1963.

A relativistic three-body problem // Phys. Lett. 1964. V.13. No.1. P.76–77. Bibl.: 4.
Co-author: D.Stoyanov.

Quasi-potential method in quantum field theory // Proc. Int. Winter School in Theor. Phys. (Dubna, 1964). Dubna, 1964. V.2. P.66–79. Bibl.: 2.

Quasi-potential approach in quantum field theory // Proc. XII Int. Conf. on High Energy Physics (Dubna, 1964). M., 1966. V.1. P.222–224. Bibl.: 7.
Co-authors: A.A.Logunov, R.N.Faustov.

Relativistically covariant equations for two particles in quantum field theory // JINR preprint E2-3498, Dubna, 1967. 24 p. Bibl.: 7.
Co-author: V.A.Matveev, R.M.Muradyan.

Relativistically covariant equations for particles in quantum field theory // JINR preprint P2-3900, Dubna, 1968. 20 p. Bibl.: 3.
Co-authors: V.A.Matveev, R.M.Muradyan.

Three-dimensional formulation of relativistic two-body problem // Topics in Elementary Particle Theory: Proc. of the Int. Seminar (Varna, 1968). P2-4050, Dubna, 1968. P.173–196. Bibl.: 35.
Co-author: V.G.Kadyshevsky.

Relativistic quasipotential model of particle scattering at high energies // Phys. Lett. 1969. V.29B. No.3. P.191–192. Bibl.: 7.
Co-authors: V.R.Garsevanishvili, V.A.Matveev, L.A.Slepchenko.

Quasipotential method in relativistic two-body problem // Problems of Theoretical Physics: Collection Dedicated to the 60th Anniversary of N.N.Bogolyubov. M., 1969. P.261–277. Bibl.: 44.
Co-author: V.G.Kadyshevsky.

Straight-line particle path approximation in the description of high energy hadron scattering in quantum field theory // J. Teor. Mat. Fiz. 1970. V.5. No.3. P.330–342. Bibl.: 43.
Co-authors: B.M.Barbashov, S.P.Kuleshov, V.A.Matveev, V.N.Pervushin, A.N.Sissakian.

Exchange quasipotential for the high energy $\pi^{\pm}p$-scattering and the problem of a linearity of the Regge trajectories // Proc. XV Int. Conf. on High Energy Physics (Kiev, 1970): Abstract of contributions. Kiev, 1970. V.2. P.514. Bibl.: 4; JINR preprint E-2-5226, Dubna, 1970. Bibl.: 4.
Co-authors: V.A.Matveev, L.A.Slepchenko.

Dynamics of two-body and quasi-two-body processes at high energies // Proc. XV Int. Conf. on High Energy Physics (Kiev, 1970): Rapporteurs talks. 5454, Dubna, 1970. V.1. P.487–490.

Quasipotential theory of high energy hadron scattering // Phys. Rev. 1971. V.4D. No.3. P.849–861. Bibl.: 40.
Co-authors: V.R.Garsevanishvili, V.A.Matveev, L.A.Slepchenko.

Corrections to eikonal approximation in quasi-potential approach // J. Teor. Mat. Fiz. 1971. V.6. No.1. P.36–41.
Co-authors: V.R.Garsevanishvili, S.V.Goloskokov, V.A.Matveev, L.A.Slepchenko.

The problem of quasi-potential smoothness in quantum field theory models // Nuovo Cim. 1971. V.4A. No.1. P.182–186. Bibl.: 13.
Co-authors: B.M.Barbashov, S.P.Kuleshov, V.A.Matveev, A.N.Sissakian.

On the representation of the scattering amplitudes in the form of the continual integrals in quantum field theory // J. Teor. Mat. Fiz. 1971. V.9. No.1. P.44–59. Bibl.: 30.
Co-author: V.A.Matveev.

Quasi-potential description of binary hadron reactions at high energies // Proc. Int. Seminar «Binary Reactions of Hadrons at High Energies» (Dubna, 1971). Dubna, 1972. P.440–465. Bibl.: 31.
Co-author: V.A.Matveev.

Straight-line path approximation in quantum field theory // Fiz. Elem. Chast. Atom. Yad. 1974. V.5. No.1. P.1–62. Bibl.: 37.
Co-authors: S.P.Kuleshov, V.A.Matveev, A.N.Sissakian, M.A.Smondyrev.

Method of straight-line paths and the eikonal problem // J. Teor. Mat. Fiz. 1974. V.18. No.2. P.147–160. Bibl.: 10.
Co-authors: S.P.Kuleshov, V.A.Matveev, A.N.Sissakian, M.A.Smondyrev.

The eikonal problem and the asymptotic quasi-potential // Phys. Fennica. 1974. V.9. P.151–165.
Co-authors: S.P.Kuleshov, V.A.Matveev, A.N.Sissakian, M.A.Smondyrev.

Straight-line path method in quantum field theory // Report Series in Physics, Univ. of Helsinki. 1974. No.80.
Co-authors: S.P.Kuleshov, V.A.Matveev, A.N.Sissakian, M.A.Smondyrev.

Twisted eikonal graphs and structure of the quasi-potential // J. Teor. Mat. Fiz. 1974. V.21. No.1. P.30–36. Bibl.: 9.
Co-authors: S.P.Kuleshov, V.A.Matveev, A.N.Sissakian, M.A.Smondyrev.

Relativistic form factors of composite particles // J. Teor. Mat. Fiz. 1975. V.23. No.3. P.310–321. Bibl.: 16.
Co-authors: V.R.Garsevanishvili, A.N.Kvinikhidze, V.A.Matveev, R.N.Faustov.

Scattering of composite particles and quasi-potential approach in quantum field theory // J. Teor. Mat. Fiz. 1975. V.25. No.1. P.37–42. Bibl.: 12.
Co-authors: V.R.Garsevanishvili, A.N.Kvinikhidze, V.A.Matveev, R.N.Faustov.

Spectral and projecting properties of the two-time n-particle Green functions in the null-plane quantum field theory // J. Teor. Mat. Fiz. 1976. V.29. No.1. P.3–17. Bibl.: 7.
Co-authors: A.N.Kvinikhidze, V.A.Matveev, A.A.Khelashvili.

Inclusive processes with large transverse momenta in the composite particle approach // Fiz. Elem. Chast. Atom. Yad. 1977. V.8. No.3. P.478–543. Bibl.: 64.
Co-authors: A.N.Kvinikhidze, A.N.Sissakian, L.A.Slepchenko.

Power falloff behaviour of the high-p_T inclusive cross sections // JINR preprint E2-11581, Dubna, 1978. 23 p. Bibl.: 25.
Co-authors: N.S.Amaglobeli, A.N.Kvinikhidze, V.A.Matveev, A.N.Sissakian, L.A.Slepchenko, Yu.V.Tevzadze.

Discrete eigenvalues with positive binding energies in quantum field theory // Preprint TMI-P-07-1991, Tbilisi, 1991. 24 p. Bibl.: 13. Co-authors: A.A.Khelashvili, L.G.Vachnadze.

Light-front formalism in quasi-potential approach in quantum field theory // Fiz. Elem. Chast. Atom. Yad. 1999. V.30. No.3. P.613–659. Bibl.: 49.
Co-author: V.R.Garsevanishvili.

3. Finite-Energy (FE) Sum Rules and Duality

A. Tavkhelidze, together with A. Logunov and L. Soloviev obtained FE sum rules for the meson–nucleon scattering amplitude and on their basis established the property of global duality: integral relations between the resonance part of the scattering amplitude and Regge parameters. The property of global and local (Venziano) duality served as the basis for formulating the string model of hadrons. Further, in collaboration with N. Krasnikov and K. Chetyrkin, the method of FE sum rules was generalized to the case of quantum chromodynamics with the use of the property of asymptotic freedom, characteristic of this theory.

FE sum rules represent a nonperturbative method widely applied for calculations in quantum chromodynamics.

Dispersion sum rules and SU(3) symmetry // Phys. Lett. 1966. V.23. No.2. P.146–148. Bibl.: 3.
Co-authors: V.A.Matveev, B.V.Struminsky.

Dispersion sum rules and high energy scattering // Phys. Lett. 1967. V.24B. No.4. P.181–182. Bibl.: 11.
Co-authors: A.A.Logunov, L.D.Soloviev.

Adler–Weisberger relation and dispersion sum rules in the theory of strong interactions // Nuovo Cim. 1967. V.48A. No.l. P.132–139. Bibl.: 12.
Co-authors: N.N.Bogolyubov, V.A.Matveev.

To the problem of dispersion sum rules // JINR preprint P2-3198, Dubna, 1967. 11 p. Bibl.: 10.
Co-authors: V.G.Kadyshevsky, R.M.Mir-Kasimov.

Dispersion sum rules and high-energy πN scattering // Phys. Lett. 1967. V.25B. No.5. P.341–343. Bibl.: 13.
Co-authors: V.A.Mescheriakov, K.V.Rerikh, V.I.Zhuravlev.

Dispersion sum rules in the theory of strong interactions // Kiev preprint, 1967; JINR preprint P2-3118, Dubna, 1967. 57 p. Bibl.: 45.
Co-authors: V.A.Matveev, L.D.Soloviev, B.V.Struminsky, V.P.Shelest.

Veneziano's representation and perturbation theory // JINR preprint E2-4844, Dubna, 1969. 8 p. Bibl.: 6.
Co-authors: V.A.Matveev.

Perturbation theory, finite-energy sum rules and a generalized Veneziano representation // Phys. Lett. 1970. V.32B. No.1. P.61–64. Bibl.: 13.
Co-authors: V.A.Matveev, D.Ts.Stoyanov.

Coherent state method in the problems of high energy hadron interactions // JINR preprint E2-5141, Dubna, 1970. 24 p. Bibl.: 35.
Co-author: V.A.Matveev.

Duality and finite energy sum rules // J. Teor. Mat. Fiz. 1970. V.4. No.1. P.11–17. Bibl.: 16. Co-authors: V.A.Matveev, D.Ts.Stoyanov.

A method of coherent states and diagram technique for dual amplitudes // JINR preprint E2-5182, Dubna, 1970. 24 p. Bibl.: 16.
Co-authors: A.N.Kvinikhidze, B.L.Markovski, D.Ts.Stoyanov.

Method of coherent states and factorization of dual amplitudes // J. Teor. Mat. Fiz. 1971. V.6. No.2. P.166–179. Bibl.: 15.
Co-authors: A.N.Kvinikhidze, B.L.Markovski, D.Ts.Stoyanov.

On approximate γ_5-invariance in the strong interaction theory // Dokl. Akad. Nauk. 1962. V.142. No.2. P.317–318. Bibl.: 4.
Co-authors: A.A.Logunov, V.A.Mescheriakov.

Oscillatory levels of a particle as a result of strong interaction with the field // JINR preprint E2-5850, Dubna, 1971. 35 p. Bibl.: 13.
Co-authors: E.P.Solodovnikova, O.A.Khrustalev.

The Bogolubov transformation in strong coupling theory // JINR preprint E2-5976, Dubna, 1971. 29 p.
Co-authors: E.P.Solodovnikova, O.A.Khrustalev.

N.N.Bogoliubov's transformation in the strong coupling theory (II) // J. Teor. Mat. Fiz. 1972. V.11. No.3. P.317–330. Bibl.: 8.
Co-authors: E.P.Solodovnikova, O.A.Khrustalev.

The Bogoliubov transformation in the strong coupling theory (III) // J. Teor. Mat. Fiz. 1972. V.12. No.2. P.164–178. Bibl.: 4.
Co-authors: O.A.Khrustalev, E.P.Solodovnikova.

Two-body problem in the adiabatic and strong coupling // J. Teor. Mat. Fiz. 1974. V.21. No.1. P.13–29. Bibl.: 2.
Co-author: E.P.Solodovnikova.

Construction of effective potential in quantum field theory at finite temperature // J. Teor. Mat. Fiz. 1976. V.26. No.2. P.172–174. Bibl.: 5.
Co-authors: N.V.Krasnikov, V.A.Matveev, K.G.Chetyrkin.

Spontaneous symmetry breaking in the case of massive scalar particles // INR preprint П-0057. 1977. 5 p. Bibl.: 3.
Co-author: N.V.Krasnikov.

5. Quantum Number Colour. A Physical Model of Hadrons as Bound States of Coloured Quarks

In 1965, A.Tavkhelidze, together with N.Bogoliubov and B.Struminsky, independently of Nambu and Han, put forward a hypothesis suggesting the existence of a new quark quantum number, subsequently termed «colour». According to this hypothesis each sort of quarks with a given flavour may be in three unitarily equivalent states corresponding to three colour values. At the same time, a principle was formulated for the selection of physical states of quantum systems, describing observable mesons and baryons, that is consistent with the requirement that hadron states be colourless. It was also noted that coloured quarks may have both fractional and integer electric charges. In the latter case colour symmetry should be violated, at least in electromagnetic (EM) interactions.

Unlike the Gell-Mann–Zweig quark model, coloured quarks within the Bogoliubov–Tavkhelidze dynamic approach were considered to be fundamental physical particles — fermions existing inside hadrons in a quasi-free state. The calculated within this approach EM- and weak form factors of hadrons, the EM-decay widths of mesons were confirmed experimentally, which justified the hypothesis of quasi-free quarks underlying the dynamic model.

Within the framework of the model of quasi-independent quarks, formulae were obtained for the «Matveev–Muradyan–Tavkhelidze rules for quark counting», according to which at large energies and momentum transfers the elastic scattering amplitude and hadron form factors exhibit a power behaviour in the large momentum. The exponent, here, is expressed in terms of the total number of quarks composing the particles that participate in the reactions. Generalization of the formulae for quark counting to other processes involving hadrons and leptons and their experimental test is an essential stage in the understanding of the physical nature of coloured quarks and of the quark structure of hadrons.

The dynamic quark model of hadrons served as the basis for attempts at relativistic generalization of the $SU(6)$ symmetry of elementary particles and led to the formulation of relativistically covariant equations for bound particle systems in quantum field theory (joint works with V. Kadyshevsky, R. Muradyan, Nguen Van Hieu, I. Todorov).

For the question of the composite models in the elementary particle physics // JINR preprint D-1968, Dubna, 1965. 12 p. Bibl.: 5.
Co-authors: N.N.Bogolyubov, B.V.Struminsky.

Relativistic invariant equations for the composite particles and form factors (I) // JINR preprint D-2075, Dubna, 1965. 15 p. Bibl.: 8.
Co-authors: N.N.Bogolyubov, Nguen van Hieu, D.Stoyanov, B.V.Struminsky, V.P.Shelest.

Higher symmetries and composite models of elementary particles // Proc. ICTP Seminar «High Energy and Elementary Particles» (Trieste, 1965). Vienna, 1965. P.753–762. Bibl.: 5.

Electromagnetic form factors in composite models of elementary particles (relativistic models) // Proc. ICTP Seminar «High Energy and Elementary Particles» (Trieste, 1965). Vienna, 1965. P.763–779. Bibl.: 5.

Magnetic moments of relativistic quark models of elementary particles // Phys. Lett. 1965. V.17. No.3. P.331–332. Bibl.: 3.
Co-author: H.J.Lipkin.

Some effects in quark model // JINR preprint P-2524, Dubna, 1965. 10 p. Bibl.: 6.
Co-authors: V.A.Matveev, B.V.Struminsky.

Relativistic invariant equations for the composite particles and form factors (II) // JINR preprint D-2141, Dubna, 1965. 10 p. Bibl.: 5.
Co-authors: N.N.Bogolyubov, V.A.Matveev, Nguen van Hieu, D.Stoyanov, B.V.Struminsky, V.P.Shelest.

SU(6)-symmetry and its possible generalizations // JINR preprint D-1929, Dubna, 1965. 9 p. Bibl.: 18.
Co-authors: V.G.Kadyshevsky, R.M.Muradyan, I.T.Todorov.

SU(6)-symmetry and higher angular momenta // Phys. Lett. 1965. V.15. No.2. P.180–182. Bibl.: 13.
Co-authors: V.G.Kadyshevsky, R.M.Muradyan, I.T.Todorov.

Relativistic generalization of SU(6)-symmetry // Phys. Lett. 1965. V.15. No.2. P.182–184. Bibl.: 14.
Co-authors: V.G.Kadyshevsky, R.M.Muradyan, I.T.Todorov.

On the unitarity of the S-matrix in the disturbed SL(6) symmetry // Dokl. Akad. Nauk. 1966. V.167. No.4. P.792–794. Bibl.: 12.
Co-author: Nguen van Hieu.

Relativistic invariant equations for the composite particles and form factors // Voprosy Fiziki El. Chast. Erevan, 1966. P.406–420. Bibl.: 5.
Co-authors: N.N.Bogolyubov, V.A.Matveev, Nguen van Hieu, D.Stoyanov, B.V.Struminsky, V.P.Shelest.

Leptonic decays of baryons in the universal $V-A$ theory // Yad. Fiz. 1966. V.3. No.5. P.910–917. Bibl.: 7.
Co-authors: O.G.Bokov, Nguen van Hieu, K.V.Rerikh, A.A.Khelashvili.

Algebras of currents and dispersion relations // Dokl. Akad. Nauk. 1966. V.168. No.2. P.316–317. Bibl.: 2.
Co-authors: A.V.Efremov, V.A.Matveev, A.A.Khelashvili.

Symmetry group ISL(6) as a covariant generalization of the group SU(6) // Voprosy Fiziki El. Chast. Erevan, 1966. P.377–389. Bibl.: 23.
Co-authors: V.G.Kadyshevsky, R.M.Muradyan, I.T.Todorov.

On the unitarity of the S-matrix in the disturbed SL(6) symmetry // Dokl. Akad. Nauk. 1966. V.167. No.4. P.792–794. Bibl.: 12.
Co-author: Nguen van Hieu.

Current-current interaction and pole model of the nonleptonic hyperon decays // JINR preprint P2-3254, Dubna, 1967. 7 p. Bibl.: 4.
Co-authors: Y.Niri, B.V.Struminsky.

Quarks and composite models of elementary particles // Proc. Int. School «High Energy Physics and Elementary Particle Theory» (Yalta, 1966). Kiev, 1967. P.635–638. Bibl.: 17.
Co-author: B.V.Struminsky.

Simplest dynamic models of composite particles // Fundamental Problems in Elementary Particle Physics: Proc. of XIV Conf. on Phys. at the Univ. of Brussels (Brussels, 1967). London, 1968. P.145–154. Bibl.: 2.

Dynamical moments of composite particles in quantum field theory // Topics in Elementary Particle Theory: Proc. of the Int. Seminar (Varna, 1968). P2-4050, Dubna, 1968. P.269–279. Bibl.: 9.
Co-authors: N.N.Bogolyubov, V.A.Matveev.

Field algebra and $SU(2)\times SU(3)\times T_{24}$ symmetry group // JINR preprint P2-3858, Dubna, 1968. 10 p. Bibl.: 6.
Co-authors: V.A.Matveev, R.M.Muradyan.

Collective resonance phenomenon in hadronic systems // JINR preprint E2-8742, Dubna, 1975. 9 p. Bibl.: 3.
Co-authors: V.A.Kuzmin, V.M.Lobashev, V.A.Matveev.

A minimal generalization of 5-quark model of Ψ-particles // Phys. Lett. 1976. V.63B. No.2. P.209–210. Bibl.: 11; Pisma v JETF. 1976. V.23. No.9. P.543–545.
Co-authors: K.G.Chetyrkin, N.V.Krasnikov, V.A.Kuzmin.

High transverse momentum processes in composite models // Proc. XVIII Int. Conf. on High Energy Physics (Tbilisi, 1976). D1,2-10400, Dubna, 1977. P.A4-11–A4-15. Bibl.: 18.

Inclusive processes with large transverse momenta in the composite particle approach // Fiz. Elem. Chast. Atom. Yad. 1977. V.8. No.3. P.478–543. Bibl.: 64.
Co-authors: A.N.Kvinikhidze, A.N.Sissakian, L.A.Slepchenko.

Deep-inelastic scattering and quark structure of hadrons // Proc. Int. Conf. «Neutrino 77» (Baksan Valley, 1977). M., 1978. V.2. P.189–209. Bibl.: 21.
Co-authors: N.V.Krasnikov, K.G.Chetyrkin.

Power falloff behaviour of the high-p_T inclusive cross sections // JINR preprint E2-11581, Dubna, 1978. 23 p. Bibl.: 25.
Co-authors: N.S.Amaglobeli, A.N.Kvinikhidze, V.A.Matveev, A.N.Sissakian, L.A.Slepchenko, Yu.V.Tevzadze.

Dynamics of processes with high momentum transfer // Proc. Conf. «Fundamental Problems of Theoretical and Mathematical Physics» (Dubna, 1979). Dubna, 1979. P.291–301. Bibl.: 19.
Co-authors: S.P.Kuleshov, V.A.Matveev.

Integrally charged quarks and spontaneously broken color symmetry // Proc. Int. Seminar «Quarks'80» (Sukhumi, 1980). M., 1981. P.58–80. Bibl.: 24.

Integer charge quarks and spontaneously broken colour symmetry // J. Teor. Mat. Fiz. 1981. V.47. No.2. P.147–162. Bibl.: 15.
Co-authors: A.Yu.Ignatiev, V.A.Kuzmin, V.A.Matveev. K.G.Chetyrkin, M.E.Shaposhnikov.

Coloured scalars and new hadrons // J. Teor. Mat. Fiz. 1982. V.53. No.2. P.181–187. Bibl.: 17.
Co-authors: A.Yu.Ignatiev, V.A.Matveev, K.G.Chetyrkin, M.E.Shaposhnikov.

Coloured scalars and new hadrons // Proc. Int. Seminar «Quarks'82» (Sukhumi,1982). M., 1983. P.28–46. Bibl.: 19.
Co-authors: A.Yu.Ignatiev, V.A.Matveev, K.G.Chetyrkin, M.E.Shaposhnikov.

Coloured scalars and new hadrons // Phys. Lett. 1982. V.117B. No.3,4. P.252–256. Bibl.: 17.
Co-authors: K.G.Chetyrkin, A.Yu.Ignatiev, V.A.Matveev, M.E.Shaposhnikov.

Colored quarks // Gravitation and Elementary Particles. M., 1982. P.220–285.
Co-authors: N.N.Bogolyubov, V.A.Matveev.

Experimental complex of the meson factory linear accelerator // INR preprint П-0003. 1975. 10 p. Bibl.: 6.
Co-authors: I.Barit et al.

Meson factory is a new powerful research instrument // Vestnik AN SSSR. 1983. V.2. P.115–125. Bibl.: 4.
Co-author: V.M.Lobashov.

Color, colored quarks, quantum chromodynamics // Proc. Int. Seminar «Quarks'94». Singapore, 1995. P.3–13. Bibl.: 42.

6. Scaling Invariance of Processes at High Energies. The Principle of Automodelity

In a cycle of works performed by A. Tavkhelidze together with V. Matveev and R. Muradyan, the principle of automodelity in high energy physics was put forward (1969), and it was applied in developing a unified approach to describing phenomena of the scaling-invariant behaviour of various deep-inelastic interaction processes of leptons with hadrons.

The scaling-invariant behaviour was predicted of muon pair production processes in collisions of hadrons at high energies in the region of large invariant dimuon masses (later termed Drell–Yan processes)

A generalization is presented of the automodelity principle for strong hadron interaction processes at high energies, for example, for inclusive hadron production processes involving large transverse momenta.

In works performed together with N. Bogoliubov and V. Vladimirov (1972) within the framework of local quantum field theory, a strict basis is presented for the existence of automodel (scaling-invariant) asymptotes of deep-inelastic processes, and the precise correlation is established between the structure functions of these processes and the behaviour of the local current commutators in the vicinity of the light cone.

In subsequent works (together with E. Wieczorek, V. Matveev, and D. Robaschik), a generalization of these results is given for non-diagonal matrix elements of the T-products of local fields and amplitudes off-the-mass-shell.

On the automodel character of the asymptotic behaviour of the form factors of the electromagnetic and weak interactions // JINR preprint P2-4578, Dubna, 1969. 13 p. Bibl.: 13.
Co-authors: V.A.Matveev, R.M.Muradyan.

Muon pair creation in the strong interactions and asymptotic sum rules // JINR preprint P2-4543, Dubna, 1969. 23 p. Bibl.: 12.
Co-authors: V.A.Matveev, R.M.Muradyan.

Current commutators, vector dominance and automodelity in lepton pair creation processes in strong interactions // Vector Mesons and Electromagnetic Interactions: Proc of the Int. Seminar (Dubna, 1969). P2-4816, Dubna, 1969. P.109–136. Bibl.: 5.
Co-authors: V.A.Matveev, R.M.Muradyan.

Mass spectrum of Di-muon produced in strong interactions // JINR preprint P2-4824, Dubna, 1969. 14 p. Bibl.: 12.
Co-authors: V.A.Matveev, R.M.Muradyan.

Deep inelastic lepton-hadron interactions // Proc. Coral Gables Conf. on Fund. Interactions at High Energies II (Miami, 1970). New York, 1970. P.178–186. Bibl.: 4.

Scale invariance, current commutators and vector dominance in deep inelastic lepton-hadron interactions // JINR preprint E2-4968, Dubna, 1970. 52 p. Bibl.: 51.
Co-authors: V.A.Matveev, R.M.Muradyan.

The automodelity hypothesis and the asymptotic behaviour of strong, electromagnetic and weak interactions at high energies // JINR preprint E2-5962, Dubna, 1971. 15 p. Bibl.: 15.
Co-authors: V.A.Matveev, R.M.Muradyan.

Automodelity, current commutators and vector dominance in deep inelastic lepton-hadron interactions // Fiz. Elem. Chast. Atom. Yad. 1971. V.2. No.1. P.7–32. Bibl.: 51.
Co-authors: V.A.Matveev, R.M.Muradyan.

On automodel asymptotics in quantum field theory (II) // J. Teor. Mat. Fiz. 1972. V.12. No.3. P.305–329. Bibl.: 14.
Co-authors: N.N.Bogolubov, V.S.Vladimirov.

Automodelity in strong interactions // Lett. al Nuovo Cim. 1972. V.5. No.14. P.907–912; JINR preprint E2-6638, Dubna, 1972. 18 p. Bibl.: 11.
Co-authors: V.A.Matveev, R.M.Muradyan.

Automodelity and asymptotics on mass shell on the basis of the Jost–Lehmann–Dyson representation // J. Teor. Mat. Fiz. 1973. V.16. No.3. P.315–327. Bibl.: 8.
Co-authors: E.Wieczorek, V.A.Matveev, D.Robaschik.

Automodellism in the large-angle elastic scattering and structure of hadrons // Lett. al Nuovo Cim. 1973. V.7. No.15. P.719–723. Bibl.: 8.
Co-authors: V.A.Matveev, R.M.Muradyan.

Electromagnetic mass differences of nucleons and sum rules in the automodel region // JINR preprint E2-7028, Dubna, 1973. 9 p. Bibl.: 10.
Co-authors: B.A.Magradze, V.A.Matveev, D.Robaschik, E.Wieczorek.

Automodelity behaviour in large-angle elastic scattering and hadron structure // JINR preprint D2-7110, Dubna, 1973. 11 p. Bibl.: 8.
Co-author: V.A.Matveev.

Large-angle scattering and the quark structure of hadrons // JINR preprint E2-8048, Dubna, 1974. 10 p. Bibl.: 4.
Co-authors: V.A.Matveev, R.M.Muradyan.

Automodel solutions for matrix elements of currents in conformal-invariant theories // J. Teor. Mat. Fiz. 1975. V.22. No.1. P.3–19. Bibl.: 20.
Co-authors: E.Wieczorek, V.A.Matveev, D.Robaschik.

Automodel asymptotics of the fixed angle scattering amplitude in the framework of the Dyson–Jost–Lehmann representation // J. Teor. Mat. Fiz. 1976. V.28. No.2. P.157–171. Bibl.: 7.
Co-authors: B.Geyer, Th.Gornitz, V.A.Matveev, D.Robaschik, E.Wieczorek.

Automodel asymptotics in the high momentum transfer processes // Proc. Int. Seminar on Deep-Inelastic and Inclusive Processes (Sukhumi, 1975). M., 1977. P.9–20. Bibl.: 7.
Co-authors: V.A.Matveev, R.M.Muradyan.

Quark counting method for the inclusive processes // Proc. Int. Workshop «Inclusive Reactions» (Serpukhov, 1976). Serpukhov, 1977. P.300–316. Bibl.: 34.
Co-authors: A.N.Kvinikhidze, V.A.Matveev, A.N.Sissakian, L.A.Slepchenko.

Scale violations in deep inelastic lepton-hadron processes and the power law in large-p_T hadron collisions // JINR preprint E2-11580, Dubna, 1978.
Co-authors: V.A.Matveev, L.A.Slepchenko.

The quark counting rule and scale invariance phenomenon at high energies // Proc. Int. Seminar on High Energy Physics and Quantum Field Theory (Protvino, 1978). Serpukhov, 1978. V.2. P.22–30. Bibl.: 21.
Co-authors: V.A.Matveev, L.A.Slepchenko.

Quark counting rules at large p_T // JINR preprint E2-11894, Dubna, 1978. 8 p. Bibl.: 14.
Co-authors: V.A.Matveev, L.A.Slepchenko.

Method of quark counting for inclusive processes // J. Teor. Mat. Fiz. 1979. V.40. No.3. P.329–339. Bibl.: 19.
Co-authors: V.A.Matveev, R.M.Muradyan.

On automodel asymptotics in quantum field theory // Proc. Int. Conf. in Quantum Field Theory and Quantum Statistics, M., 1979.
Co-authors: N.N.Bogolyubov, V.S.Vladimirov.

Integral equation for causal distributions and their automodel asymptotics in the ladder φ^3 theory // J. Teor. Mat. Fiz. 1980. V.45. No.3. P.302–312. Bibl.: 14.
Co-authors: A.N.Kvinikhidze, B.A.Magradze, V.A.Matveev, M.A.Mestvirishvili.

Anomalous dimension quark counting at large transferred momenta in QCD // Phys. Lett. 1981. V.100B. No.1. P.75–78.
Co-authors: V.A.Matveev, L.A.Slepchenko.

7. Structure of the Ground State and Non-Conservation of the Fermion and Baryon Numbers in Gauge Theories

In a cycle of works performed by A. Tavkhelidze together with V. Matveev, V. Rubakov, V. Tokarev, M. Shaposhnikov, the problem of the instability of normal baryon matter in the extreme conditions of superhigh densities was formulated and resolved within the framework of the standard theory of electroweak interactions for the first time. In these works, the complex structure of vacuum and the strong non-conservation of fermion quantum numbers related to it were shown to be the key property of gauge interactions underlying the conclusion on the instability of superdense baryon matter.

An essentially important result of these studies is the conclusion on the possible existence in Nature of highly intense decay processes of normal matter in contact with a drop of superdense fermion matter involving a powerful release of energy. Recently, the possible existence of such phenomena has been discussed actively in connection with the construction of a new generation of colliders that provide colliding relativistic nuclei and, also, with the search of «dark» matter in the Universe.

One of the characteristic manifestations of the complex structure of vacuum in gauge field theory, demonstrated in this cycle of works making use of the precisely solvable Schwinger model — 2-dimensional quantum electrodynamics — is the degeneracy of vacuum in the fermion number and chirality, when topologically non-trivial configurations of the gauge fields are taken into account (the so-called double θ-vacuum).

On the basis of the exact operator solution of the equations of this model, the physical space was found and the ground state of the system constructed, that has no definite fermion and chiral numbers and is characterized by two arbitrary angular parameters. The condition of confinement in this model reduces to the requirement that the gauge (electric) charge operator becomes zero in the space of physical states.

Excitations of the system are described by the scalar neutral field Σ, the relation of which is established with gradient invariant local currents constructed from fermion and gauge fields. The problem of the $U(1)$ anomaly has been resolved. Both the non-conservation mechanism of the axial current and its consequences, for example, the resulting quark condensate $< \bar{\psi}\psi >$ $= 0$ and non-zero mass of the scalar Σ-particle, have been studied. It is shown that the Σ-particle permits alternative representation either as a quark–antiquark state, or as a state of pseudoscalar gluonium.

In works performed together with V. Tokarev, the method of chains of N. Bogoliubov equations was used for studying the properties of Green's functions of the gauge-invariant composite operators in the Schwinger model, and the results were applied for establishing the structure of the ground state of the model.

Within the framework of «Grand Unification» theories, A. Tavkhelidze (together with N. Krasnikov and V. Kuzmin, 1977) proposed a model of gauge interaction with a superweak *CP*-violation, which permits describing simultaneously both the effect of *CP*-violation in rare and *K*-decays and the origin of baryon asymmetry of the Universe.

Does one need the additional heavy quarks for the explanation of the observed behaviour of $R(s)$? // Pisma v JETF. 1977. V.25. No.9. P.456–459. Bibl.: 12.
Co-authors: V.A.Kuzmin, K.G.Chetyrkin.

CP-noninvariant superweak interaction and baryon asymmetry of the Universe // Proc. Int. Conf. «Neutrino 77» (Baksan Valley, 1977). M., 1978. V.2. P.293–300. Bibl.: 6.
Co-authors: A.Yu.Ignatiev, N.V.Krasnikov, V.A.Kuzmin.

Universal CP-noninvariant superweak interaction and baryon asymmetry of the Universe // Phys. Lett. 1978. V.76B. No.4. P.436–438. Bibl.: 6.
Co-authors: A.Yu.Ignatiev, N.V.Krasnikov, V.A.Kuzmin.

Structure of ground state in gauge theories: two-dimensional quantum electrodynamics // Proc. Int. Seminar «Group Theoretical Methods in Physics» (Zvenigorod, 1979). M., 1980. P.151–158. Bibl.: 10.
Co-authors: N.V.Krasnikov, V.A.Matveev, V.A.Rubakov, V.F.Tokarev.

Structure of ground state in two-dimensional massless quantum electrodynamics // J. Teor. Mat. Fiz. 1980. V.45. No.3. P.313–328. Bibl.: 18.
Co-authors: N.V.Krasnikov, V.A.Matveev, V.A.Rubakov, V.F.Tokarev.

Double-θ vacuum structure and the functional integral in the Schwinger model // Phys. Lett. 1980. V.97B. No.1. P.103–106. Bibl.: 11.
Co-authors: N.V.Krasnikov, V.A.Matveev, V.A.Rubakov, V.F.Tokarev.

Problem of P- and CP-conservation in gauge theories // Proc. Int. Conf. on Nonlocal Theories (Alushta, 1979). Dubna, 1979. P.137–147. Bibl.: 13.
Co-authors: N.V.Krasnikov, V.A.Matveev.

Problem of CP-invariance in quantum chromodynamics // Proc. Int. Seminar «Quarks'80» (Sukhumi, 1980). M., 1981. P.5–14. Bibl.: 17.
Co-authors: N.V.Krasnikov, V.A.Matveev.

Structure of ground state and properties of the Green functions of colorless operators in the Schwinger model // INR preprint П-0314. 1983. 32 p. Bibl.: 29.
Co-author: V.F.Tokarev.

The symmetry properties and dynamics of the gauge theories with scalar fields // INR preprint П-0325. 1983. 20 p. Bibl.: 17.
Co-authors: V.A.Matveev, M.E.Shaposhnikov.

The Schwinger model and sum rules // Phys. Lett. 1983. V.132B. No.4,5,6. P.402–406. Bibl.: 13.
Co-authors: A.A.Pivovarov, V.F.Tokarev.

On the operator product expansion in QED_2 // J. Teor. Mat. Fiz. 1984. V.60. No.2. P.199–205. Bibl.: 10.
Co-authors: A.A.Pivovarov, V.F.Tokarev.

The ground state structure and properties of the Green functions of colourless operators in the Schwinger model // Fiz. Elem. Chast. Atom. Yad. 1985. V.16. No.5. P.973–1004. Bibl.: 29.
Co-author: V.F.Tokarev.

Stable anomalous states of superdense matter in gauge theories // Phys. Lett. 1985. V.165B. No.1–3. P.109–112. Bibl.: 11.; J. Teor. Mat. Fiz. 1985. V.65. No.2. P.250–254. Bibl.: 11.
Co-author: V.A.Rubakov.

Canonical quantization of gauge theories with scalar condensate: scalar electrodynamics // INR preprint П-0418. 1985. 39 p. Bibl.: 22.
Co-authors: V.V.Vlasov, V.A.Matveev, S.Yu.Khlebnikov, M.E.Shaposhnikov.

Canonical quantization of gauge theories with scalar condensate: non-Abelian gauge theories // INR preprint П-0424. 1985. 17 p. Bibl.: 12.
Co-authors: V.V.Vlasov, V.A.Matveev, S.Yu.Khlebnikov, M.E.Shaposhnikov.

Fermion number nonconservation and limiting density of fermionic matter (two-dimensional gauge model) // J. Teor. Mat. Fiz. 1986. V.68. No.1. P.3–17; Proc. Int. Seminar «Quarks'86» (Tbilisi, 1986). M., 1987. P.9–30. Bibl.: 12.
Co-authors: V.A.Matveev, V.A.Rubakov, V.F.Tokarev.

Fermion number nonconservation in cold dense fermionic matter in $(V-A)$ gauge theories // J. Teor. Mat. Fiz. 1986. V.69. No.1. P.3–24. Bibl.: 21.
Co-authors: V.A.Matveev, V.A.Rubakov, V.F.Tokarev.

Canonical quantization of gauge theories with scalar condensate and the problem of spontaneous symmetry breaking // Fiz. Elem. Chast. Atom. Yad. 1987. V.18. No.1. P.5–38. Bibl.: 22.
Co-authors: V.V.Vlasov, V.A.Matveev, S.Yu.Khlebnikov, M.E.Shaposhnikov.

Fermion number nonconservation and cold neutral fermionic matter in $(V-A)$ gauge theories // Nucl. Phys. 1987. V.B282. No.3/4. P.700–726. Bibl.: 21.
Co-authors: V.A.Matveev, V.A.Rubakov, V.F.Tokarev.

Baryon number nonconservation in extreme conditions // Usp. Fiz. Nauk. 1988. V.156. No.2. P.253–295. Bibl.: 117.
Co-authors: V.A.Matveev, V.A.Rubakov, M.E.Shaposhnikov.

Ultraviolet finite quantum electrodynamics // J. Teor. Mat. Fiz. 1989. V.79. No.3. P.371–377. Bibl.: 6.
Co-author: N.V.Krasnikov.

Repulsion in the instanton gas, formation of a core in nucleon and the Bogolyubov chain method // J. Teor. Mat. Fiz. 1991. V.86. No.1. P.31–42. Bibl.: 10.
Co-authors: I.V.Musatov, V.F.Tokarev.

BIBLIOGRAPHY OF THE SCIENTIFIC WORKS OF ACADEMICIAN A.N. TAVKHELIDZE

1957

Dispersion relations for meson-nucleon scattering processes in the static nucleon approximation // Bull. Georgian Acad. Sci. 1957. V.18. No.1. P.19–24.
Co-author: A.A.Logunov.

Dispersion relations and phase shifts equations for meson-nucleon scattering processes in the static nucleon approximation // Bull. Georgian Acad. Sci. 1957. V.18. No.5. P.533–540.
Co-author: A.A.Logunov.

Dispersion relations for photoproduction reactions of π-mesons on nucleons // JETF. 1957. V.32. No.6. P.1393–1403. Bibl.: 5.
Co-author: A.A.Logunov.

On the role of bound states in the photoproduction processes // Dokl. Acad. Nauk. 1957. V.112. No.1. P.45–47. Bibl.: 2.
Co-authors: A.A.Logunov, B.M.Stepanov.

Photoproduction processes and dispersion relations // Nucl. Phys. 1957. V.4. P.427–452. Bibl.: 9.
Co-authors: A.A.Logunov, L.D.Solovyev.

1958

Approximate equations for the amplitude of photon scattering on nucleons // Dokl. Acad. Nauk. 1958. V.119. No.4. P.690–693. Bibl.: 5.
Co-author: V.K.Fedianin.

The analytical properties of the amplitude of a process involving a variable number of particles // Dokl. Acad. Nauk. 1958. V.120. No.4. P.739–742. Bibl.: 2.
Co-author: A.A.Logunov.

Problems of the theory of dispersion relations. JINR preprint P-143, Dubna, 1958. 30 p. Bibl.: 8.
Co-author: A.A.Logunov.

On the dispersion relations for the reactions with the variable particle number // Zeitschrift für Naturforschung. 1958. V.13A. No.8. P.642–644. Bibl.: 3.
Co-authors: A.A.Logunov, N.A.Chernikov.

On the renormalization group in the problems with fixed source // Nauchn. Dokl. Vys. Shk. 1958. V.2. P.169–172.

Generalized dispersion relations // Nauchn. Dokl. Vys. Shk. 1958. V.3. P.178–185.
Co-author: V.K.Fedianin.

On the theory of the dispersion relations for the complex processes // Nauchn. Dokl. Vys. Shk. 1958. V.3. P.186–195.
Co-authors: S.M.Bilenkij, A.A.Logunov.

Generalized dispersion relations // Nuovo Cimento. 1958. V.10. No.6. P.943–952. Bibl.: 6.
Co-author: A.A.Logunov.

On the theory of dispersion relations // Nuovo Cimento. 1958. V.10. No.6. P.953–964. Bibl.: 6.
Co-authors: S.M.Bilenkij, A.A.Logunov.

Some problems encountered in the theory of the dispersion relations // Nucl. Phys. 1958. V.8. P.374–393. Bibl.: 8.
Co-author: A.A.Logunov.

1959

On the question of the inverse dispersion relations // Bull. Georgian Acad. Sci. 1959. V.23. No.2. P.149–156. Bibl.: 5.
Co-author: M.A.Mestvirishvili.

The spectral properties of Green's functions in a meson field model with a fixed source // Dokl. Akad. Nauk. 1959. V.129. No.4. P.769–772. Bibl.: 7.
Co-authors: I.T.Todorov, N.A.Chernikov.

1960

Majoration of Feynman diagrams // Dokl. Akad. Nauk. 1960. V.135. No.4. P.801–804. Bibl.: 5.
Co-authors: A.A.Logunov, I.T.Todorov, N.A.Chernikov.

1961

On the fermion mass in the γ_5-invariant model of the quantum field theory // Dokl. Akad. Nauk. 1961. V.139. No.2. P.345–347. Bibl.: 6.
Co-authors: B.A.Arbuzov, R.N.Faustov.

Application of the N.I.Muskhelishvili methods for the solution of singular integral equations in quantum field theory // Problems of Continuum Mechanics. M., 1961. P.45–59. Bibl.: 8.
Co-authors: N.N.Bogolyubov, B.V.Medvedev.

1962

On approximate γ_5-invariance in the strong interaction theory // Dokl. Akad. Nauk. 1962. V.142. No.2. P.317–318. Bibl.: 4.
Co-authors: A.A.Logunov, V.A.Mescheriakov.

The asymptotic behaviour of the scattering amplitudes and the renormalization group method // Phys. Lett. 1962. V.2. No.3. P.150–152. Bibl.: 8.
Co-authors: B.A.Arbuzov, A.A.Logunov, R.N.Faustov.

Regge poles and perturbation theory I // Phys. Lett. 1962. V.2. No.7. P.305–306. Bibl.: 2.
Co-authors: B.A.Arbuzov, A.A.Logunov, R.N.Faustov, A.T.Filippov.

1963

Regge poles and perturbation theory II // Phys. Lett. 1963. V.4. No.5. P.272–273. Bibl.: 6.
Co-authors: B.A.Arbuzov, B.M.Barbashov, A.A.Logunov, Nguen van Hieu, R.N.Faustov, A.T.Filippov.

Regge poles in quantum electrodynamics // Nucl. Phys. 1963. V.44. P.275–279. Bibl.: 4.
Co-authors: A.A.Logunov, Nguen van Hieu, O.A.Khrustalev.

Regge poles and perturbation theory // Nucl. Phys. 1963. V.49. P.170–176. Bibl.: 7.
Co-authors: A.A.Logunov, Nguen van Hieu, O.A.Khrustalev.

The Regge poles and Bethe–Salpeter equations // Dokl. Akad. Nauk. 1963. V.150. No.4. P.764–766. Bibl.: 4.
Co-authors: B.A.Arbuzov, A.A.Logunov, R.N.Faustov.

Quasi-optical approach in quantum field theory // Nuovo Cim. 1963. V.29. No.2. P.380–399. Bibl.: 8.
Co-author: A.A.Logunov.

Quasi-optical model and asymptotics of scattering amplitude // JETF. 1963. V.44. No.4. P.1409–1411. Bibl.: 4.
Co-authors: B.A.Arbuzov, A.A.Logunov, R.N.Faustov, A.T.Filippov.

Quasi-potential character of the scattering amplitude // JINR preprint D-1191, Dubna, 1963. 9 p. Bibl.: 6.
Co-authors: A.A.Logunov, I.T.Todorov, O.A.Khrustalev.

Quasi-potential character of the Mandelstam representation // Phys. Lett. 1963. V.4. No.6. P.325–326. Bibl.: 2.
Co-authors: A.A.Logunov, O.A.Khrustalev.

Lectures on quasipotential method in field theory // Proc. Summer School in Theoretical Physics (Bangalore, 1963). Bombay, 1963.

1964

A relativistic three-body problem // Phys. Lett. 1964. V.13. No.1. P.76–77. Bibl.: 4.
Co-author: D.Stoyanov.

Quasi-potential method in quantum field theory // Proc. Int. Winter School in Theor. Phys. (Dubna, 1964). Dubna, 1964. V.2. P.66–79. Bibl.: 2.

An investigation into the analytical properties of the scattering amplitude in the non-relativistic three-body problem // Dokl. Akad. Nauk. 1964. V.158. No.6. P.1302–1305. Bibl.: 7.
Co-authors: I.Sh.Vashakidze, R.M.Muradyan, G.A.Chilashvili, V.P.Shelest.

On an investigation of the analytic properties of the scattering amplitudes in the non-relativistic three-body problem II // JINR preprint E-1659, Dubna, 1964. 10 p. Bibl.: 5.
Co-authors: G.A.Chilashvili, R.M.Muradyan, V.P.Shelest.

1965

For the question of the composite models in the elementary particle physics // JINR preprint D-1968, Dubna, 1965. 12 p. Bibl.: 5.
Co-authors: N.N.Bogolyubov, B.V.Struminsky.

Some effects in quark model // JINR preprint P-2524, Dubna, 1965. 10 p. Bibl.: 6.
Co-authors: V.A.Matveev, B.V.Struminsky.

Relativistic invariant equations for the composite particles and form factors (I) // JINR preprint D-2075, Dubna, 1965. 15 p. Bibl.: 8.
Co-authors: N.N.Bogolyubov, Nguen van Hieu, D.Stoyanov, B.V.Struminsky, V.P.Shelest.

Relativistic invariant equations for the composite particles and form factors (II) // JINR preprint D-2141, Dubna, 1965. 10 p. Bibl.: 5.
Co-authors: N.N.Bogolyubov, V.A.Matveev, Nguen van Hieu, D.Stoyanov, B.V.Struminsky, V.P.Shelest.

Higher symmetries and composite models of elementary particles // Proc. ICTP Seminar «High Energy and Elementary Particles» (Trieste, 1965). Vienna, 1965. P.753–762. Bibl.: 5.

Electromagnetic form factors in composite models of elementary particles (relativistic models) // Proc. ICTP Seminar «High Energy and Elementary Particles» (Trieste, 1965). Vienna, 1965. P.763–779. Bibl.: 5.

SU(6)-symmetry and its possible generalizations // JINR preprint D-1929, Dubna, 1965. 9 p. Bibl.: 18.
Co-authors: V.G.Kadyshevsky, R.M.Muradyan, I.T.Todorov.

SU(6)-symmetry and higher angular momenta // Phys. Lett. 1965. V.15. No.2. P.180–182. Bibl.: 13.
Co-authors: V.G.Kadyshevsky, R.M.Muradyan, I.T.Todorov.

Relativistic generalization of SU(6)-symmetry // Phys. Lett. 1965. V.15. No.2. P.182–184. Bibl.: 14.
Co-authors: V.G.Kadyshevsky, R.M.Muradyan, I.T.Todorov.

Magnetic moments of relativistic quark models of elementary particles // Phys. Lett. 1965. V.17. No.3. P.331–332. Bibl.: 3.
Co-author: H.J.Lipkin.

1966

Quasi-potential approach in quantum field theory // Proc. XII Int. Conf. on High Energy Physics (Dubna, 1964). M., 1966. V.1. P.222–224. Bibl.: 7.
Co-authors: A.A.Logunov, R.N.Faustov.

On the unitarity of the S-matrix in the disturbed SL(6) symmetry // Dokl. Akad. Nauk. 1966. V.167. No.4. P.792–794. Bibl.: 12.
Co-author: Nguen van Hieu.

Relativistic invariant equations for the composite particles and form factors // Voprosy Fiziki El. Chast. Erevan, 1966. P.406–420. Bibl.: 5.
Co-authors: N.N.Bogolyubov, V.A.Matveev, Nguen van Hieu, D.Stoyanov, B.V.Struminsky, V.P.Shelest.

Leptonic decays of baryons in the universal $V-A$ theory // Yad. Fiz. 1966. V.3. No.5. P.910–917. Bibl.: 7.
Co-authors: O.G.Bokov, Nguen van Hieu, K.V.Rerikh, A.A.Khelashvili.

Algebras of currents and dispersion relations // Dokl. Akad. Nauk. 1966. V.168. No.2. P.316–317. Bibl.: 2.
Co-authors: A.V.Efremov, V.A.Matveev, A.A.Khelashvili.

Dispersion sum rules and SU(3) symmetry // Phys. Lett. 1966. V.23. No.2. P.146–148. Bibl.: 3.
Co-authors: V.A.Matveev, B.V.Struminsky.

Symmetry group ISL(6) as a covariant generalization of the group SU(6) // Voprosy Fiziki El. Chast. Erevan, 1966. P.377–389. Bibl.: 23.
Co-authors: V.G.Kadyshevsky, R.M.Muradyan, I.T.Todorov.

On an investigation of the analytic properties of the scattering amplitude in the non-relativistic three-body problem // Proc. XII Int. Conf. on High Energy Physics (Dubna, 1964). M., 1966. V.1. P.386–387. Bibl.: 8.
Co-authors: I.Sh.Vashakidze, R.M.Muradyan, G.A.Chilashvili.

1967

Current-current interaction and pole model of the nonleptonic hyperon decays // JINR preprint P2-3254, Dubna, 1967. 7 p. Bibl.: 4.
Co-authors: Y.Niri, B.V.Struminsky.

To the problem of dispersion sum rules // JINR preprint P2-3198, Dubna, 1967. 11 p. Bibl.: 10.
Co-authors: V.G.Kadyshevsky, R.M.Mir-Kasimov.

Quarks and composite models of elementary particles // Proc. Int. School «High Energy Physics and Elementary Particle Theory» (Yalta, 1966). Kiev, 1967. P.635–638. Bibl.: 17.
Co-author: B.V.Struminsky.

Adler–Weisberger relation and dispersion sum rules in the theory of strong interactions // Nuovo Cim. 1967. V.48A. No.1. P.132–139. Bibl.: 12.
Co-authors: N.N.Bogolyubov, V.A.Matveev.

Dispersion sum rules and high energy scattering // Phys. Lett. 1967. V.24B. No.4. P.181–182. Bibl.: 11.
Co-authors: A.A.Logunov, L.D.Soloviev.

Dispersion sum rules and high-energy πN scattering // Phys. Lett. 1967. V.25B. No.5. P.341–343. Bibl.: 13.
Co-authors: V.A.Mescheriakov, K.V.Rerikh, V.I.Zhuravlev.

Dispersion sum rules in the theory of strong interactions // Kiev preprint, 1967; JINR preprint P2-3118, Dubna, 1967. 57 p. Bibl.: 45.
Co-authors: V.A.Matveev, L.D.Soloviev, B.V.Struminsky, V.P.Shelest.

Relativistically covariant equations for two particles in quantum field theory // JINR preprint E2-3498, Dubna, 1967. 24 p. Bibl.: 7.
Co-author: V.A.Matveev, R.M.Muradyan.

Electromagnetic interactions of hadrons in quark model // Proc. Int. Conf. on Electromagnetic Interactions at Low and Intermediate Energies (Dubna, 1967). V.1. P.102–110. Bibl.: 12.
Co-author: B.V.Struminsky.

1968

Field algebra and $SU(2)\times SU(3)\times T_{24}$ symmetry group // JINR preprint P2-3858, Dubna, 1968. 10 p. Bibl.: 6.
Co-authors: V.A.Matveev, R.M.Muradyan.

Three-dimensional formulation of relativistic two-body problem // Topics in Elementary Particle Theory: Proc. of the Int. Seminar (Varna, 1968). P2-4050, Dubna, 1968. P.173–196. Bibl.: 35.
Co-author: V.G.Kadyshevsky.

Dynamical moments of composite particles in quantum field theory // Topics in Elementary Particle Theory: Proc. of the Int. Seminar (Varna, 1968). P2-4050, Dubna, 1968. P.269–279. Bibl.: 9.
Co-authors: N.N.Bogolyubov, V.A.Matveev.

Cuts in the complex l-plane and inelastic cross sections // Yad. Fiz. 1968. V.7. No.1. P.166–169. Bibl.: 5.
Co-authors: Dao vong Duc, Nguen van Hieu.

Relativistically covariant equations for particles in quantum field theory // JINR preprint P2-3900, Dubna, 1968. 20 p. Bibl.: 3.
Co-authors: V.A.Matveev, R.M.Muradyan.

Simplest dynamic models of composite particles // Fundamental Problems in Elementary Particle Physics: Proc. of XIV Conf. on Phys. at the Univ. of Brussels (Brussels, 1967). London, 1968. P.145–154. Bibl.: 2.

1969

Quasipotential method in relativistic two-body problem // Problems of Theoretical Physics: Collection Dedicated to the 60th Anniversary of N.N. Bogolyubov. M., 1969. P.261–277. Bibl.: 44.
Co-author: V.G.Kadyshevsky.

Current commutators, vector dominance and automodelity in lepton pair creation processes in strong interactions // Vector Mesons and Electromagnetic Interactions: Proc. of the Int. Seminar (Dubna, 1969). P2-4816, Dubna, 1969. P.109–136. Bibl.: 5.
Co-authors: V.A.Matveev, R.M.Muradyan.

On the automodel character of the asymptotic behaviour of the form factors of the electromagnetic and weak interactions // JINR preprint P2-4578, Dubna, 1969. 13 p. Bibl.: 13.
Co-authors: V.A.Matveev, R.M.Muradyan.

Muon pair creation in the strong interactions and asymptotic sum rules // JINR preprint P2-4543, Dubna, 1969. 23 p. Bibl.: 12.
Co-authors: V.A.Matveev, R.M.Muradyan.

Mass spectrum of Di-muon produced in strong interactions // JINR preprint P2-4824, Dubna, 1969. 14 p. Bibl.: 12.
Co-authors: V.A.Matveev, R.M.Muradyan.

Relativistic quasipotential model of particle scattering at high energies // Phys. Lett. 1969. V.29B. No.3. P.191–192. Bibl.: 7.
Co-authors: V.R.Garsevanishvili, V.A.Matveev, L.A.Slepchenko.

Veneziano's representation and perturbation theory // JINR preprint E2-4844, Dubna, 1969. 8 p. Bibl.: 6.
Co-authors: V.A.Matveev.

1970

Scale invariance, current commutators and vector dominance in deep inelastic lepton-hadron interactions // JINR preprint E2-4968, Dubna, 1970. 52 p. Bibl.: 51.
Co-authors: V.A.Matveev, R.M.Muradyan.

Duality and finite energy sum rules // J. Teor. Mat. Fiz. 1970. V.4. No.1. P.11–17. Bibl.: 16.
Co-authors: V.A.Matveev, D.Ts.Stoyanov.

Straight-line particle path approximation in the description of high energy hadron scattering in quantum field theory // J. Teor. Mat. Fiz. 1970. V.5. No.3. P.330–342. Bibl.: 43.
Co-authors: B.M.Barbashov, S.P.Kuleshov, V.A.Matveev, V.N.Pervushin, A.N.Sissakian.

A method of coherent states and diagram technique for dual amplitudes // JINR preprint E2-5182, Dubna, 1970. 24 p. Bibl.: 16.
Co-authors: A.N.Kvinikhidze, B.L.Markovski, D.Ts.Stoyanov.

Coherent state method in the problems of high energy hadron interactions // JINR preprint E2-5141, Dubna, 1970. 24 p. Bibl.: 35.
Co-author: V.A.Matveev.

Deep inelastic lepton-hadron interactions // Proc. Coral Gables Conf. on Fund. Interactions at High Energies II (Miami, 1970). New York, 1970. P.178–186. Bibl.: 4.

Exchange quasipotential for the high energy $\pi^{\pm}p$-scattering and the problem of a linearity of the Regge trajectories // Proc. XV Int. Conf. on High Energy Physics (Kiev, 1970): Abstr. of contributions. Kiev, 1970. V.2. P.514. Bibl.: 4; JINR preprint E-2-5226, Dubna, 1970. Bibl.: 4.
Co-authors: V.A.Matveev, L.A.Slepchenko.

Perturbation theory, finite-energy sum rules and a generalized Veneziano representation // Phys. Lett. 1970. V.32B. No.1. P.61–64. Bibl.: 13.
Co-authors: V.A.Matveev, D.Ts.Stoyanov.

Problem of quasi-potential smoothness in quantum field theory models // Phys. Lett. 1970. V.33B. No.6. P.419–421. Bibl.: 13.
Co-authors: B.M.Barbashov, S.P.Kuleshov, V.A.Matveev, A.N.Sissakian.

Quasi-potential approach and particle scattering at high energies // Proc. XV Int. Conf. on High Energy Physics (Kiev, 1970): Abstr. of contributions. Kiev, 1970. V.2. P.464. Bibl.: 3.
Co-authors: V.R.Garsevanishvili, V.A.Matveev, L.A.Slepchenko.

Dynamics of two-body and quasi-two-body processes at high energies // Proc. XV Int. Conf. on High Energy Physics (Kiev, 1970): Rapporteurs talks. 5454, Dubna, 1970. V.1. P.487–490.

Quasi-potential approach to isobar production processes at high energies // Proc. XV Int. Conf. on High Energy Physics (Kiev, 1970): Abstr. of contributions. Kiev, 1970. V.2. P.513. Bibl.: 5.
Co-authors: V.R.Garsevanishvili, V.A.Matveev, L.A.Slepchenko.

Automodelity, current algebra and vector dominance in deep inelastic lepton-hadron interactions // Proc. XV Int. Conf. on High Energy Physics (Kiev, 1970): Abstr. of contributions. Kiev, 1970. V.2. P.695.
Co-authors: V.A.Matveev, L.A.Slepchenko.

On the real part of the elastic scattering amplitude at high energies // Proc. XV Int. Conf. on High Energy Physics (Kiev, 1970): Abstr. of contributions. Kiev, 1970. V.2. P.465. Bibl.: 2.
Co-authors: V.R.Garsevanishvili, S.V.Goloskokov, V.A.Matveev, L.A.Slepchenko.

1971

Automodelity, current commutators and vector dominance in deep inelastic lepton-hadron interactions // Fiz. Elem. Chast. Atom. Yad. 1971. V.2. No.1. P.7–32. Bibl.: 51.
Co-authors: V.A.Matveev, R.M.Muradyan.

Method of coherent states and factorization of dual amplitudes // J. Teor. Mat. Fiz. 1971. V.6. No.2. P.166–179. Bibl.: 15.
Co-authors: A.N.Kvinikhidze, B.L.Markovski, D.Ts.Stoyanov.

On the representation of the scattering amplitudes in the form of the continual integrals in quantum field theory // J. Teor. Mat. Fiz. 1971. V.9. No.1. P.44–59. Bibl.: 30.
Co-author: V.A.Matveev.

Construction of dual amplitudes with the help of finite set of oscillator-type operators // Proc. Int. Symp. on High Energy Physics (Dresden, 1971). D1-5969, Dubna, 1971. P.579–587. Bibl.: 7.
Co-authors: A.N.Kvinikhidze, B.L.Markovski, C.D.Popov, D.Ts.Stoyanov.

The Bogolubov transformation in strong coupling theory // JINR preprint E2-5976, Dubna, 1971. 29 p.
Co-authors: E.P.Solodovnikova, O.A.Khrustalev.

Corrections to eikonal approximation in quasi-potential approach // J. Teor. Mat. Fiz. 1971. V.6. No.1. P.36–41.
Co-authors: V.R.Garsevanishvili, S.V.Goloskokov, V.A.Matveev, L.A.Slepchenko.

Factorization of dual amplitudes in the model with the finite set of oscillators and loops // JINR preprint E2-5695, Dubna, 1971. 24 p. Bibl.: 8.
Co-authors: A.N.Kvinikhidze, C.D.Popov, D.Ts.Stoyanov.

The automodelity hypothesis and the asymptotic behaviour of strong, electromagnetic and weak interactions at high energies // JINR preprint E2-5962, Dubna, 1971. 15 p. Bibl.: 15.
Co-authors: V.A.Matveev, R.M.Muradyan.

Factorization of dual amplitudes and loops in the coherent state model // JINR preprint E2-5568, Dubna, 1971. 10 p. Bibl.: 8.
Co-authors: A.N.Kvinikhidze, C.D.Popov, D.Ts.Stoyanov.

Oscillatory levels of a particle as a result of strong interaction with the field // JINR preprint E2-5850, Dubna, 1971. 35 p. Bibl.: 13.
Co-authors: E.P.Solodovnikova, O.A.Khrustalev.

Quasipotential theory of high energy hadron scattering // Phys. Rev. 1971. V.4D. No.3. P.849–861. Bibl.: 40.
Co-authors: V.R.Garsevanishvili, V.A.Matveev, L.A.Slepchenko.

The problem of quasi-potential smoothness in quantum field theory models // Nuovo Cim. 1971. V.4A. No.1. P.182–186. Bibl.: 13.
Co-authors: B.M.Barbashov, S.P.Kuleshov, V.A.Matveev, A.N.Sissakian.

1972

Automodel behaviour at high energies // Proc. Int. Seminar «Hadron Interactions at High Energies». Baku, 1972. P.8.
Co-authors: V.A.Matveev, R.M.Muradyan.

Group-theoretical meaning of dual transformations in the space of coherent states // J. Teor. Mat. Fiz. 1972. V.12. No.3. P.370–383. Bibl.: 9.
Co-authors: C.D.Popov, D.Ts.Stoyanov.

Dual amplitudes and SL(2,R) symmetries // Proc. Int. Seminar «Hadron Interactions at High Energies», Baku, 1972. P.17.
Co-authors: A.N.Kvinikhidze, C.D.Popov, D.Ts.Stoyanov.

Quasipotential description of binary hadron reactions at high energies // Proc. Int. Seminar «Binary Reactions of Hadrons at High Energies» (Dubna, 1971). Dubna, 1972. P.440–465. Bibl.: 31.
Co-author: V.A.Matveev.

A method of coherent states and diagram technique for dual amplitudes // Proc. Int. Seminar «Binary Reactions of Hadrons at High Energies» (Dubna, 1971). Dubna, 1972. P.755–768. Bibl.: 8.
Co-authors: A.N.Kvinikhidze, B.L.Markovski, C.D.Popov, D.Ts.Stoyanov.

On automodel asymptotics in quantum field theory (I) // J. Teor. Mat. Fiz. 1972. V.12. No.1. P.3–17. Bibl.: 13.
Co-authors: N.N.Bogolyubov, V.S.Vladimirov.

On automodel asymptotics in quantum field theory (II) // J. Teor. Mat. Fiz. 1972. V.12. No.3. P.305–329. Bibl.: 14.
Co-authors: N.N.Bogolubov, V.S.Vladimirov.

Oscillator levels of the particle as a consequence of strong interaction with the field // J. Teor. Mat. Fiz. 1972. V.10. No.2. P.162–181. Bibl.: 13.
Co-authors: E.P.Solodovnikova, O.A.Khrustalev.

N.N.Bogoliubov's transformation in the strong coupling theory (II) // J. Teor. Mat. Fiz. 1972. V.11. No.3. P.317–330. Bibl.: 8.
Co-authors: E.P.Solodovnikova, O.A.Khrustalev.

The Bogoliubov transformation in the strong coupling theory (III) // J. Teor. Mat. Fiz. 1972. V.12. No.2. P.164–178. Bibl.: 4.
Co-authors: O.A.Khrustalev, E.P.Solodovnikova.

$\pi - N$ scattering at high energies in the quasi-potential approach // Proc. Int. Seminar «Hadron Interactions at High Energies». Baku, 1972. P.3.
Co-authors: V.R.Garsevanishvili, S.V.Goloskokov, V.A.Matveev.

SL(2,R) symmetry of the dual two-particle amplitudes // J. Teor. Mat. Fiz. 1972. V.13. No.2. P.145–173. Bibl.: 28.
Co-authors: C.D.Popov, D.Ts.Stoyanov.

Automodel and on-mass shell asymptotics according to the Dyson–Jost–Lehmann representation // JINR preprint E2-6792, Dubna, 1972. 27 p. Bibl.: 7.
Co-authors: V.A.Matveev, D.Robaschik, E.Wieczorek.

Automodelity in strong interactions // Lett. al Nuovo Cim. 1972. V.5. No.14. P.907–912; JINR preprint E2-6638, Dubna, 1972. 18 p. Bibl.: 11.
Co-authors: V.A.Matveev, R.M.Muradyan.

Dynamics of the two-body and quasi-two-body processes at high energies // XV Int. Conf. on High Energy Physics (Kiev, 1970). Kiev, 1972. P.367–414. Bibl.: p. 410–414.

1973

Automodelity behaviour in large-angle elastic scattering and hadron structure // JINR preprint D2-7110, Dubna, 1973. 11 p. Bibl.: 8.
Co-author: V.A.Matveev.

Automodelity in strong interactions // J. Teor. Mat. Fiz. 1973. V.15. No.3. P.332–339. Bibl.: 11.
Co-authors: V.A.Matveev, R.M.Muradyan.

Automodelity and asymptotics on mass shell on the basis of the Jost–Lehmann–Dyson representation // J. Teor. Mat. Fiz. 1973. V.16. No.3. P.315–327. Bibl.: 8.
Co-authors: E.Wieczorek, V.A.Matveev, D.Robaschik.

Application of the N.I.Muskhelishvili methods in the theory of elementary particles // Proc. Symposium on Continuum Mechanics and Related Problems of Analysis (Tbilisi, 1971). Tbilisi, 1973. V.1. P.5–11.
Co-authors: N.N.Bogolyubov, V.A.Mescheryakov.

Automodellism in the large-angle elastic scattering and structure of hadrons // Lett. al Nuovo Cim. 1973. V.7. No.15. P.719–723. Bibl.: 8.
Co-authors: V.A.Matveev, R.M.Muradyan.

Electromagnetic mass differences of nucleons and sum rules in the automodel region // JINR preprint E2-7028, Dubna, 1973. 9 p. Bibl.: 10.
Co-authors: B.A.Magradze, V.A.Matveev, D.Robaschik, E.Wieczorek.

Straight-line path method and the eikonal problem // JINR preprint E2-7041, Dubna, 1973. 27 p. Bibl.: 10.
Co-authors: S.P.Kuleshov, V.A.Matveev, A.N.Sissakian, M.A.Smondyrev.

1974

Two-body problem in the adiabatic and strong coupling // J. Teor. Mat. Fiz. 1974. V.21. No.1. P.13–29. Bibl.: 2.
Co-author: E.P.Solodovnikova.

Method of straight-line paths and the eikonal problem // J. Teor. Mat. Fiz. 1974. V.18. No.2. P.147–160. Bibl.: 10.
Co-authors: S.P.Kuleshov, V.A.Matveev, A.N.Sissakian, M.A.Smondyrev.

Twisted eikonal graphs and structure of the quasi-potential // J. Teor. Mat. Fiz. 1974. V.21. No.1. P.30–36. Bibl.: 9.
Co-authors: S.P.Kuleshov, V.A.Matveev, A.N.Sissakian, M.A.Smondyrev.

Straight-line path approximation in quantum field theory // Fiz. Elem. Chast. Atom. Yad. 1974. V.5. No.1. P.1–62. Bibl.: 37.
Co-authors: S.P.Kuleshov, V.A.Matveev, A.N.Sissakian, M.A.Smondyrev.

Large-angle scattering and the quark structure of hadrons // JINR preprint E2-8048, Dubna, 1974. 10 p. Bibl.: 4.
Co-authors: V.A.Matveev, R.M.Muradyan.

Straight-line path method in quantum field theory // Report Series in Physics, Univ. of Helsinki. 1974. No.80.
Co-authors: S.P.Kuleshov, V.A.Matveev, A.N.Sissakian, M.A.Smondyrev.

The eikonal problem and the asymptotic quasi-potential // Phys. Fennica. 1974. V.9. P.151–165.
Co-authors: S.P.Kuleshov, V.A.Matveev, A.N.Sissakian, M.A.Smondyrev.

1975

Automodel solutions for matrix elements of currents in conformal-invariant theories // J. Teor. Mat. Fiz. 1975. V.22. No.1. P.3–19. Bibl.: 20.
Co-authors: E.Wieczorek, V.A.Matveev, D.Robaschik.

Selection rules for dual resonance states // J. Teor. Mat. Fiz. 1975. V.22. No.2. P.147–158. Bibl.: 8.
Co-authors: C.D.Popov, D.Ts.Stoyanov.

Scattering of composite particles and quasi-potential approach in quantum field theory // J. Teor. Mat. Fiz. 1975. V.25. No.1. P.37–42. Bibl.: 12.
Co-authors: V.R.Garsevanishvili, A.N.Kvinikhidze, V.A.Matveev, R.N.Faustov.

Relativistic form factors of composite particles // J. Teor. Mat. Fiz. 1975. V.23. No.3. P.310–321. Bibl.: 16.
Co-authors: V.R.Garsevanishvili, A.N.Kvinikhidze, V.A.Matveev, R.N.Faustov.

Experimental complex of the meson factory linear accelerator // INR preprint П-0003. 1975. 10 p. Bibl.: 6.
Co-authors: I.Barit et al.

Collective resonance phenomenon in hadronic systems // JINR preprint E2-8742, Dubna, 1975. 9 p. Bibl.: 3.
Co-authors: V.A.Kuzmin, V.M.Lobashev, V.A.Matveev.

1976

Automodel asymptotics of the fixed angle scattering amplitude in the framework of the Dyson–Jost–Lehmann representation // J. Teor. Mat. Fiz. 1976. V.28. No.2. P.157–171. Bibl.: 7.
Co-authors: B.Geyer, Th.Gornitz, V.A.Matveev, D.Robaschik, E.Wieczorek.

A minimal generalization of 5-quark model of Ψ-particles // Phys. Lett. 1976. V.63B. No.2. P.209–210. Bibl.: 11; Pisma v JETF. 1976. V.23. No.9. P.543–545.
Co-authors: K.G.Chetyrkin, N.V.Krasnikov, V.A.Kuzmin.

Construction of effective potential in quantum field theory at finite temperature // J. Teor. Mat. Fiz. 1976. V.26. No.2. P.172–174. Bibl.: 5.
Co-authors: N.V.Krasnikov, V.A.Matveev, K.G.Chetyrkin.

Spectral and projecting properties of the two-time n-particle Green functions in the null-plane quantum field theory // J. Teor. Mat. Fiz. 1976. V.29. No.1. P.3–17. Bibl.: 7.
Co-authors: A.N.Kvinikhidze, V.A.Matveev, A.A.Khelashvili.

Quark counting method for the inclusive processes // JINR preprint D2-10297, Dubna, 1976. 20 p. Bibl.: 34.
Co-authors: A.N.Kvinikhidze, V.A.Matveev, A.N.Sissakian, L.A.Slepchenko.

1977

High transverse momentum processes in composite models // Proc. XVIII Int. Conf. on High Energy Physics (Tbilisi, 1976). D1,2-10400, Dubna, 1977. P.A4-11–A4-15. Bibl.: 18.

Automodel asymptotics in the high momentum transfer processes // Proc. Int. Seminar on Deep-Inelastic and Inclusive Processes (Sukhumi, 1975). M., 1977. P.9–20. Bibl.: 7.
Co-authors: V.A.Matveev, R.M.Muradyan.

Inclusive processes with large transverse momenta in the composite particle approach // Fiz. Elem. Chast. Atom. Yad. 1977. V.8. No.3. P.478–543. Bibl.: 64.
Co-authors: A.N.Kvinikhidze, A.N.Sissakian, L.A.Slepchenko.

Quark counting method for the inclusive processes // Proc. Int. Workshop «Inclusive Reactions» (Serpukhov, 1976). Serpukhov, 1977. P.300–316. Bibl.: 34.
Co-authors: A.N.Kvinikhidze, V.A.Matveev, A.N.Sissakian, L.A.Slepchenko.

Does one need the additional heavy quarks for the explanation of the observed behaviour of $R(s)$? // Pisma v JETF. 1977. V.25. No.9. P.456–459. Bibl.: 12.
Co-authors: V.A.Kuzmin, K.G.Chetyrkin.

Spontaneous symmetry breaking in the case of massive scalar particles // INR preprint П-0057. 1997. 5 p. Bibl.: 3.
Co-author: N.V.Krasnikov.

1978

Asymptotic behavior of the cross section of e^+-e^- annihilation into hadrons and finite energy sum rules in quantum chromodynamics // Proc. V Int. Seminar on High Energy Physics Problems (Dubna, 1978). Dubna, 1978. P.13–19. Bibl.: 7.
Co-authors: N.V.Krasnikov, K.G.Chetyrkin.

Finite energy sum rules for the cross section of e^+-e^- annihilation into hadrons in quantum chromodynamics // J. Teor. Mat. Fiz. 1978. V.35. No.2. P.147–150. Bibl.: 18.
Co-authors: N.V.Krasnikov, K.G.Chetyrkin.

Scale violations in deep inelastic lepton-hadron processes and the power law in large-p_T hadron collisions // JINR preprint E2-11580, Dubna, 1978.
Co-authors: V.A.Matveev, L.A.Slepchenko.

The quark counting rule and scale invariance phenomenon at high energies // Proc. Int. Seminar on High Energy Physics and Quantum Field Theory (Protvino, 1978). Serpukhov, 1978. V.2. P.22–30. Bibl.: 21.
Co-authors: V.A.Matveev, L.A.Slepchenko.

CP-noninvariant superweak interaction and baryon asymmetry of the Universe // Proc. Int. Conf. «Neutrino 77» (Baksan Valley, 1977). M., 1978. V.2. P.293–300. Bibl.: 6.
Co-authors: A.Yu.Ignatiev, N.V.Krasnikov, V.A.Kuzmin.

Deep-inelastic scattering and quark structure of hadrons // Proc. Int. Conf. «Neutrino 77» (Baksan Valley, 1977). M., 1978. V.2. P.189–209. Bibl.: 21.
Co-authors: N.V.Krasnikov, K.G.Chetyrkin.

Finite energy sum rules for the cross section of e^+-e^- annihilation into hadrons in QCD // Phys. Lett. 1978. V.76B. No.1. P.83–84. Bibl.: 15.
Co-authors: K.G.Chetyrkin, N.V.Krasnikov.

Power falloff behaviour of the high-p_T inclusive cross sections // JINR preprint E2-11581, Dubna, 1978. 23 p. Bibl.: 25.
Co-authors: N.S.Amaglobeli, A.N.Kvinikhidze, V.A.Matveev, A.N.Sissakian, L.A.Slepchenko, Yu.V.Tevzadze.

Quark counting rules at large p_T // JINR preprint E2-11894, Dubna, 1978. 8 p. Bibl.: 14.
Co-authors: V.A.Matveev, L.A.Slepchenko.

Universal CP-noninvariant superweak interaction and baryon asymmetry of the Universe // Phys. Lett. 1978. V.76B. No.4. P.436–438. Bibl.: 6.
Co-authors: A.Yu.Ignatiev, N.V.Krasnikov, V.A.Kuzmin.

1979

Dynamics of processes with high momentum transfer // Proc. Conf. «Fundamental Problems of Theoretical and Mathematical Physics» (Dubna, 1979). Dubna, 1979. P.291–301. Bibl.: 19.
Co-authors: S.P.Kuleshov, V.A.Matveev.

Method of quark counting for inclusive processes // J. Teor. Mat. Fiz. 1979. V.40. No.3. P.329–339. Bibl.: 19.
Co-authors: V.A.Matveev, R.M.Muradyan.

Cross sections for the e^+-e^- annihilation into hadrons in quantum field theory // Proc. Hadron Structure 77. Bratislava, 1979. P.185–196. Bibl.: 24.
Co-authors: K.G.Chetyrkin, N.V.Krasnikov.

On automodel asymptotics in quantum field theory // Proc. Int. Conf. in Quantum Field Theory and Quantum Statistics, M., 1979.
Co-authors: N.N.Bogolyubov, V.S.Vladimirov.

Problem of P- and CP-conservation in gauge theories // Proc. Int. Conf. on Nonlocal Theories (Alushta, 1979). Dubna, 1979. P.137–147. Bibl.: 13.
Co-authors: N.V.Krasnikov, V.A.Matveev.

1980

Integral equation for causal distributions and their automodel asymptotics in the ladder φ^3 theory // J. Teor. Mat. Fiz. 1980. V.45. No.3. P.302–312. Bibl.: 14.
Co-authors: A.N.Kvinikhidze, B.A.Magradze, V.A.Matveev, M.A.Mestvirishvili.

Structure of ground state in gauge theories: two-dimensional quantum electrodynamics // Proc. Int. Seminar «Group Theoretical Methods in Physics» (Zvenigorod, 1979). M., 1980. P.151–158. Bibl.: 10.
Co-authors: N.V.Krasnikov, V.A.Matveev, V.A.Rubakov, V.F.Tokarev.

Structure of ground state in two-dimensional massless quantum electrodynamics // J. Teor. Mat. Fiz. 1980. V.45. No.3. P.313–328. Bibl.: 18.
Co-authors: N.V.Krasnikov, V.A.Matveev, V.A.Rubakov, V.F.Tokarev.

Double-θ vacuum structure and the functional integral in the Schwinger model // Phys. Lett. 1980. V.97B. No.1. P.103–106. Bibl.: 11.
Co-authors: N.V.Krasnikov, V.A.Matveev, V.A.Rubakov, V.F.Tokarev.

1981

Problem of CP-invariance in quantum chromodynamics // Proc. Int. Seminar «Quarks'80» (Sukhumi, 1980). M., 1981. P.5–14. Bibl.: 17.
Co-authors: N.V.Krasnikov, V.A.Matveev.

Integrally charged quarks and spontaneously broken color symmetry // Proc. Int. Seminar «Quarks'80» (Sukhumi, 1980). M., 1981. P.58–80. Bibl.: 24.

Integer charge quarks and spontaneously broken colour symmetry // J. Teor. Mat. Fiz. 1981. V.47. No.2. P.147–162. Bibl.: 15.
Co-authors: A.Yu.Ignatiev, V.A.Kuzmin, V.A.Matveev, K.G.Chetyrkin, M.E.Shaposhnikov.

Anomalous dimension quark counting at large transferred momenta in QCD // Phys. Lett. 1981. V.100B. No.1. P.75–78.
Co-authors: V.A.Matveev, L.A.Slepchenko.

1982

The use of finite energy sum rules for the description of the baryon properties in QCD, estimation of the proton lifetime in the $SU(5)$ model // Pisma v JETF. 1982. V.36. No.7. P.272–275. Bibl.: 12.
Co-authors: N.V.Krasnikov, A.A.Pivovarov.

Structure of ground state in the modified Schwinger model // J. Teor. Mat. Fiz. 1982. V.51. No.2. P.192–200. Bibl.: 13.
Co-author: V.F.Tokarev.

Coloured scalars and new hadrons // J. Teor. Mat. Fiz. 1982. V.53. No.2. P.181–187. Bibl.: 17.
Co-authors: A.Yu.Ignatiev, V.A.Matveev, K.G.Chetyrkin, M.E.Shaposhnikov.

Coloured scalars and new hadrons // Phys. Lett. 1982. V.117B. No.3,4. P.252–256. Bibl.: 17.
Co-authors: K.G.Chetyrkin, A.Yu.Ignatiev, V.A.Matveev, M.E.Shaposhnikov.

Colored quarks // Gravitation and Elementary Particles. M., 1982. P.220–285.
Co-authors: N.N.Bogolyubov, V.A.Matveev.

1983

Meson factory is a new powerful research instrument // Vestnik AN SSSR. 1983. V.2. P.115–125. Bibl.: 4.
Co-author: V.M.Lobashov.

The symmetry properties and dynamics of the gauge theories with scalar fields // INR preprint П-0325. 1983. 20 p. Bibl.: 17.
Co-authors: V.A.Matveev, M.E.Shaposhnikov.

Structure of ground state and properties of the Green functions of colorless operators in the Schwinger model // INR preprint П-0314. 1983. 32 p. Bibl.: 29.
Co-author: V.F.Tokarev.

Coloured scalars and new hadrons // Proc. Int. Seminar «Quarks'82» (Sukhumi, 1982). M., 1983. P.28–46. Bibl.: 19.
Co-authors: A.Yu.Ignatiev, V.A.Matveev, K.G.Chetyrkin, M.E.Shaposhnikov.

The Schwinger model and sum rules // Phys. Lett. 1983. V.132B. No.4,5,6. P.402–406. Bibl.: 13.
Co-authors: A.A.Pivovarov, V.F.Tokarev.

1984

On the operator product expansion in QED_2 // J. Teor. Mat. Fiz. 1984. V.60. No.2. P.199–205. Bibl.: 10.
Co-authors: A.A.Pivovarov, V.F.Tokarev.

Symmetry properties and dynamics of the gauge theories with scalar fields // J. Teor. Mat. Fiz. 1984. V.59. No.3. P.323–344. Bibl.: 17.
Co-authors: V.A.Matveev, M.E.Shaposhnikov.

1985

Canonical quantization of gauge theories with scalar condensate: scalar electrodynamics // INR preprint П-0418. 1985. 39 p. Bibl.: 22.
Co-authors: V.V.Vlasov, V.A.Matveev, S.Yu.Khlebnikov, M.E.Shaposhnikov.

Canonical quantization of gauge theories with scalar condensate: non-Abelian gauge theories // INR preprint П-0424. 1985. 17 p. Bibl.: 12.
Co-authors: V.V.Vlasov, V.A.Matveev, S.Yu.Khlebnikov, M.E.Shaposhnikov.

Stable anomalous states of superdense matter in gauge theories // Phys. Lett. 1985. V.165B. No.1–3. P.109–112. Bibl.: 11.; J. Teor. Mat. Fiz. 1985. V.65. No.2. P.250–254. Bibl.: 11.
Co-author: V.A.Rubakov.

The ground state structure and properties of the Green functions of colourless operators in the Schwinger model // Fiz. Elem. Chast. Atom. Yad. 1985. V.16. No.5. P.973–1004. Bibl.: 29.
Co-author: V.F.Tokarev.

1986

Fermion number nonconservation and limiting density of fermionic matter (two-dimensional gauge model) // J. Teor. Mat. Fiz. 1986. V.68. No.1. P.3–17. Bibl.: 12.
Co-authors: V.A.Matveev, V.A.Rubakov, V.F.Tokarev.

Fermion number nonconservation in cold dense fermionic matter in $(V-A)$ gauge theories // J. Teor. Mat. Fiz. 1986. V.69. No.1. P.3–24. Bibl.: 21.
Co-authors: V.A.Matveev, V.A.Rubakov, V.F.Tokarev.

1987

Canonical quantization of gauge theories with scalar condensate and the problem of spontaneous symmetry breaking // Fiz. Elem. Chast. Atom. Yad. 1987. V.18. No.1. P.5–38. Bibl.: 22.
Co-authors: V.V.Vlasov, V.A.Matveev, S.Yu.Khlebnikov, M.E.Shaposhnikov.

Fermion number nonconservation and limiting density of fermionic matter: two-dimensional gauge model // Proc. Int. Seminar «Quarks'86» (Tbilisi, 1986). M., 1987. P.9–30. Bibl.: 12.
Co-authors: V.A.Matveev, V.A.Rubakov, V.F.Tokarev.

Fermion number nonconservation and cold neutral fermionic matter in $(V-A)$ gauge theories // Nucl. Phys. 1987. V.B282. No.3/4. P.700–726. Bibl.: 21.
Co-authors: V.A.Matveev, V.A.Rubakov, V.F.Tokarev.

1988

Baryon number nonconservation in extreme conditions // Usp. Fiz. Nauk. 1988. V.156. No.2. P.253–295. Bibl.: 117.
Co-authors: V.A.Matveev, V.A.Rubakov, M.E.Shaposhnikov.

1989

Ultraviolet finite quantum electrodynamics // J. Teor. Mat. Fiz. 1989. V.79. No.3. P.371–377. Bibl.: 6.
Co-author: N.V.Krasnikov.

1990

Vacuum structure in gauge theories with colourless variables // Fiz. Elem. Chast. Atom. Yad. 1990. V.21. No.5. P.1126–1186. Bibl.: 38.
Co-author: V.F.Tokarev.

1991

Repulsion in the instanton gas, formation of a core in nucleon and the Bogolyubov chain method // J. Teor. Mat. Fiz. 1991. V.86. No.1. P.31–42. Bibl.: 10.
Co-authors: I.V.Musatov, V.F.Tokarev.

Discrete eigenvalues with positive binding energies in quantum field theory // Preprint TMI-P-07-1991, Tbilisi, 1991. 24 p. Bibl.: 13.
Co-authors: A.A.Khelashvili, L.G.Vachnadze.

1995

Color, colored quarks, quantum chromodynamics // Proc. Int. Seminar «Quarks'94». Singapore, 1995. P.3–13. Bibl.: 42.

1999

Light-front formalism in quasi-potential approach in quantum field theory // Fiz. Elem. Chast. Atom. Yad. 1999. V.30. No.3. P.613–659. Bibl.: 49.
Co-author: V.R.Garsevanishvili.

N.N. Bogolyubov and Modern Particle Physics. JINR preprint D2-99-289, Dubna, 1999. 6 p.
Co-author: V.A.Matveev

2000

N.N.Bogolyubov and Modern Particle Physics // International School in Physics and Mathematics: Annual report (Tbilisi, 1999). Tbilisi, 2000. P.5–8.
Co-author: V.A.Matveev.

MAIN DATES OF THE LIFE AND SCIENTIFIC ACTIVITY OF ACADEMICIAN A.N. TAVKHELIDZE

1930, December 16	Born in Tbilisi.
1948	Graduated from Tbilisi high school No.8 for boys.
1953	Graduated from physical faculty of Tbilisi State University.
1956	Completed postgraduate studies at the V.A. Steklov Mathematical Institute of the USSR Academy of Sciences (Moscow).
1956–1970	Worked at the Joint Institute for Nuclear Research (Dubna) as researcher, Head of department, Deputy Director of the Laboratory of Theoretical Physics.
1957	Received a Candidate of Sciences degree at the V.A. Steklov Mathematical Institute of the USSR Academy of Sciences (Moscow) for thesis «Photoproduction of π mesons on nucleons».
1963	At the Joint Institute for Nuclear Research presented thesis «Quasi-potential approach in quantum field theory» and received a Doctor of Sciences degree.
1965–1970	Worked also as Head of theoretical physics group at the Institute of High Energies (Protvino).
1967–1971	Worked also as Head of Department of Elementary Particle Physics at the N.N. Bogoliubov Institute of Theoretical Physics of the Ukrainian Academy of Sciences (Kiev).
1967	Elected corresponding member of the Georgian Academy of Sciences.
1967–1990	Member of Higher Attestation Commission at the USSR Government.
1967–1991	Deputy Editor-in-Chief of the journal «Theoretical and Mathematical Physics» of the USSR Academy of Sciences.
1970–1986	Director of the Institute of Nuclear Research of the USSR Academy of Sciences (Moscow). Professor of the M.V. Lomonosov Moscow State University.
1971*	Head of Theoretical Physics Department of the A.M. Razmadze Mathematical Institute of the Georgian Academy of Sciences (Tbilisi).
1971	Awarded the Order of the Red Banner.

*Till now.

1973	Awarded USSR State prize for the cycle of studies «Photoproduction of π mesons on nucleons».
1974	Elected full member of the Georgian Academy of Sciences.
1974–1990	Member of Committee for Lenin and State prizes at the USSR Government.
1978	Awarded the Order of October Revolution.
1982	Conferred title of «Distinguished Figure of Science of Georgian SSR».
1984	Elected corresponding member of the USSR Academy of Sciences.
1986*	President of the Georgian Academy of Sciences.
1986*	Chairman of the Georgian Committee for State prizes in science and technology under the management of the President of Georgia.
	Editor-in-Chief of the journal «Communications of the Georgian Academy of Sciences».
1987*	Head of Theoretical Physics Department — Scientific leader of the Institute of Nuclear Research of the Russian Academy of Sciences.
	Professor of the I.A. Javakhishvili Tbilisi State University.
1987	Entry made in the State register for discoveries of the Soviet Union of discovery «Matveev–Muradyan–Tavkhelidze rules for quark counting».
1987–1990	Deputy of Supreme Soviet of Georgian SSR of the eleventh assembly and member of Presidium of Supreme Soviet of Georgian SSR.
1988	Awarded Lenin prize for the cycle of investigations «New quantum number – colour and establishment of regularities in the quark structure of elementary particles and atomic nuclei».
1989	Elected USSR People's Deputy.
1990	Elected full member (academician) of the USSR Academy of Sciences (Russian Academy of Sciences since 1991).
1990*	Member of Editorial board of the journal «Physics of Elementary Particles and Atomic Nuclei» published by the Joint Institute for Nuclear Research.
1991*	Leader of Georgian group of the Pugwash movement.
1992*	Member of the Scientific Council of the Joint Institute for Nuclear Research.
1995*	Director of the Institute of High Energy Physics of the I.A. Javakhishvili Tbilisi State University.
	Director of Georgian branch of the World Federation of Scientists.
1996*	Awarded the N.N. Bogoliubov prize of the Ukrainian National Academy of Sciences.

*Till now.

1998 Awarded State prize of the Russian Federation in science and technology for «creation of the Baksan neutrino observatory and research in neutrino astrophysics, elementary particle and cosmic ray physics».

Awarded by the International Association of Academies of Sciences a Gold medal for his great contribution to the strengthening of international scientific collaboration.

1999 Awarded the Order of Friendship (Russian Federation).

2000 Conferred the title of «Honorary Doctor of the Joint Institute for Nuclear Research».

A.N.Tavkhelidze

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