Nonlinear theory of elementary particles: 4.The intermediate bosons and mass generation theory

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The purpose of this chapter of nonlinear theory of elementary particles (NTEP) is to describe the mechanism of generation of massive elementary particles. The theory, presented below, indicates the possibility of the particle mass production by means of massive intermediate boson, but without the presence of Higgs's boson. It is shown that nonlinearity is critical for the appearance of particles' masses.

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1.0. The postulate of generation of massive elementary particles

The purpose of this chapter is to describe the mechanism of generation of massive elementary particles on the basis of the hypotheses, accepted in the chapter (Kyriakos, 2010a). Here, the mass-free particle, the photon, i.e. a quantum of an electromagnetic field, serves as a "billet" for the generation of a massive particle. In this case, the appearance of the mass of a particle is identical to the generation of the massive particle itself.

There is a mechanism in the theory of Standard Model (SM) that ensures the generation of currents of elementary particles. This mechanism is known as the gauge (or phase) transformation of particles' field (let's recall that the particle's field in QFT is the particle's wave function).

In the SM there is also a mechanism that ensures the generation of masses of elementary particles. Here, all particles do not have a mass at the initial stage. In the SM, the mass-free particles acquire mass because of the spontaneous breakdown of the gauge symmetry of vacuum. This mechanism is called Higgs's mechanism.

In the framework of axiomatic nonlinear elementary particle theory we accepted (see (Kyriakos, 2010a)) the following basic *postulates, which ensure the generation of massive particles*:

1) *In the proposed theory, in contrast to SM, only a quantum of an electromagnetic wave (photon) does not have mass.*

2) *The fields of an electromagnetic wave quantum (photon) can under specified conditions undergo a rotation transformation and initial symmetry breaking, which generate different massive elementary particles.*

It follows from these hypothesis that the equations of elementary particles must be nonlinear modifications of the equations of quantized electromagnetic (EM) waves. The detailed analysis presented in the following chapters shows that because of the rotation transformation and different types of symmetry breaking of the initial photon, such elementary particles can have mass, electric charge, spin (which is a multiple of 1 and ½), helicity, chirality, and all other characteristics of existing elementary particles.

In this chapter we will show that this transformation is accomplished through the massive intermediate boson by means of the rotation transformation and the spontaneous symmetry breaking of mass-free photon. Here the simplest type of intermediate boson - neutral boson - will be examined (subsequently we will examine the more complex cases of generation of the charged intermediate bosons).

Note that the mathematical description of mass generation of elementary particles in NTEP and in SM according with Higgs's mechanism has many similarities. We will look at how nonlinear theory makes it possible to explain many features of this mechanism.

2.0. Photon as a gauge field

As one of the simplest examples of the generation of massive fields (particles) we can consider the photoproduction of the electron-positron pair:

$$\gamma + p \rightarrow e^+ + e^- + p \ , \qquad (4.2.1)$$

Actually, the photon γ is a mass-free gauge vector boson. The EM field of proton p (or some atom nucleous) initiates its transformation into two massive particles: electron and positron, *but its EM field does not disappear, similarly to Higgs's field***.** The fields of the electron and positron e^+, e^- are spinors, which are not transformed like vector fields. *Thus, we can say that the reaction* (4.2.1) *describes the process of symmetry breaking of the initial mass-free vector field in order to generate the massive spinor particles.*

Let us examine the Feynman diagram of the above reaction of a pair production (Fig. 4.1):

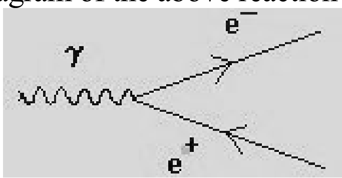

Fig. 4.1

It is known that using Feynman's diagrams within the framework of SM, we can precisely calculate all characteristics of particles with the exception of charge and mass. Nevertheless, the reaction (4.2.1) remains mysterious: we do not know, for example, how the process of transformation of the mass-free boson field into the massive fields happens, and how the electrical charge appears.

Within the framework of SM the interaction of the particles' currents takes place in the vertex of the diagram. However, it is obvious that here, before the electron-positron production occurs, the transformation of a mass-free photon into massive electron-positron pair begins. This means that the interaction, which here occurs between the photon field and the proton (or nuclear) field, is the origin of this transformation. We ask, what kind of transformation could this be? There are several considerations that allow us to answer this question.

In order to allow this transformation, Higgs's theory states that the intermediate (massive) bosons must participate. In other words, we can assume that the generation of electron and positron masses in this scenario occurs through some virtual intermediate massive photon.

On the other hand it is known that the propagation of EM wave in the strong electromagnetic fields is accompanied by nonlinear effects. On this base it is possible to assume that the photon must undergo a certain nonlinear transformation. And as we postulated above, this is a transformation of rotation.

Based on this evidence, let us assume that in the vertex of the Feynman's diagram the rotation transformation of the "linear" photon (in the sense that it obeys a linear wave equation) into the "nonlinear" photon (which obeys a nonlinear wave equation), which acquires rest mass, is achieved.

Thus, during the first stage, the rotation transformation of the mass-free photon into the intermediate boson (i.e. into a special "massive" photon) must occur in the strong EM field of the proton. Then during the second stage (which we will consider in the following chapter), the transformation of massive boson into two massive fermions must take place. Obviously, in this case the initial symmetry of the photon will be broken, since two massive "nonlinear" spinor particles are "born" from the mass-free "linear" vector photon.

These ideas can be translated into mathematical language. Let us now describe the rotation transformation of a photon.

3.0. The rotation transformation of electromagnetic wave quantum

First, we recall the quantum equation of a "linear" photon, obtained in the previous chapter (see (Kyriakos, 2010b)).

3.1. Quantum equation of the photon

For certainty, we will examine the same circularly polarized photon moving along the y - axis. The Feynman diagram's lines of the photon (i.e. the "linear" electromagnetic quantum) γ correspond to linear wave equations (3.2.5) of the previous chapter:

$$\left[\left(\hat{\alpha}_o\hat{\varepsilon}\right)^2 - c^2\left(\hat{\vec{\alpha}}\hat{\vec{p}}\right)^2\right]\Phi = 0 \,, \qquad \text{(a)}$$

or, to the equivalent system (3.2.7) of the same chapter:

$$\begin{cases} \Phi^+\left(\hat{\alpha}_o\hat{\varepsilon} - c\hat{\vec{\alpha}}\ \hat{\vec{p}}\right) = 0 \\ \left(\hat{\alpha}_o\hat{\varepsilon} + c\hat{\vec{\alpha}}\ \hat{\vec{p}}\right)\ \Phi = 0 \end{cases}, \qquad \text{(b)}$$

where $\hat{\varepsilon} = i\hbar\frac{\partial}{\partial t}, \hat{\vec{p}} = -i\hbar\vec{\nabla}$ are the operators of energy and momentum, correspondingly, $\left\{\hat{\alpha}_0, \hat{\vec{\alpha}}\right\}$ are Dirac's matrixes and $\vec{\Phi}(y)$ is the matrix (3.2.8), which contains the components of wave function of photon:

$$\Phi = \begin{pmatrix} \Phi_1 \\ \Phi_2 \\ \Phi_3 \\ \Phi_4 \end{pmatrix} = \begin{pmatrix} \mathrm{E}_x \\ \mathrm{E}_z \\ i\mathrm{H}_x \\ i\mathrm{H}_z \end{pmatrix}, \qquad \text{(c)}$$

3.2. The rotation transformation of photon fields

The rotation transformation of the "linear" photon wave to a "curvilinear" one can be conditionally written in the following form:

$$\hat{R}\Phi \rightarrow \Phi', \qquad (4.3.1)$$

where $\hat{R}$ is the rotation operator (see (Kyriakos, 2009; Kyriakos, 2010c)) for the transformation of a photon wave from linear state to curvilinear state, and Φ' is some final wave function:

$$\Phi' = \begin{pmatrix} \Phi'_1 \\ \Phi'_2 \\ \Phi'_3 \\ \Phi'_4 \end{pmatrix} = \begin{pmatrix} \mathrm{E}'_x \\ \mathrm{E}'_z \\ i\mathrm{H}'_x \\ i\mathrm{H}'_z \end{pmatrix}, \qquad (4.3.2)$$

which appears after the nonlinear transformation (4.3.1); here, $\left(\mathrm{E}'_x \quad \mathrm{E}'_z \quad -i\mathrm{H}'_x \quad -i\mathrm{H}'_z\right)$ are electromagnetic field vectors after the rotation transformation, which correspond to the wave functions Φ'.

It is known that the transition of vector motion from linear to curvilinear state is described by differential geometry (Eisenhart, 1960). Note also that this transition is mathematically equivalent to a vector transition from flat space to curvilinear space, which is described by Riemann geometry. In relation to this, let us remind ourselves that the Pauli matrices, as well as the photon matrices, are the space rotation operators – 2-D and 3-D accordingly (Ryder, 1985).

3.3. The rotation transformation description in differential geometry

We do not know the real structure of a photon as a quantum of an EM wave. However, we have an idea about the description of the structure of its fields and their motion. Therefore, in the following, the word "photon" should be understood only in the sense of the known mathematical description of photon fields' characteristics.

Let us consider a plane-polarized EM wave, which has the field vectors $(\mathrm{E}_x, \mathrm{H}_z)$ (see fig. 4.2):

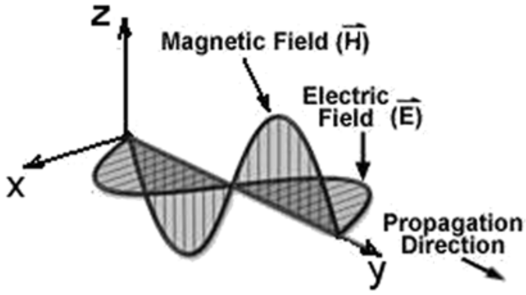

Fig. 4.2

Let this wave is rotated, by some radius r_p, in the plane (X', O', Y') of a fixed co-ordinate system (X', Y', Z', O') around the axis Z', so that E_x is parallel to the plane (X', O', Y'), and H_z is perpendicular to this plane (fig. 4.3).

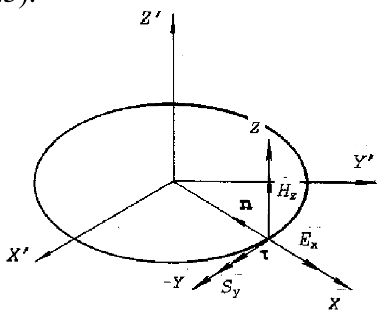

Fig. 4.3

According to Maxwell (Jackson, 1999), the following term of equations (b)

$$\hat{\alpha}_0 \hat{\varepsilon} \Phi = i\hbar \frac{\partial \Phi}{\partial t}$$

contains the Maxwell's displacement current, which is defined by the expression:

$$j_{dis} = \frac{1}{4\pi} \frac{\partial \vec{\mathrm{E}}}{\partial t}, \qquad . \quad (4.3.3)$$

The electrical field vector $\vec{\mathrm{E}}$ above, which moves along the curvilinear trajectory (assume its direction is from the center), can be written in the form:

$$\vec{\mathrm{E}} = -\mathrm{E} \cdot \vec{n}, \qquad (4.3.4)$$

where $\mathrm{E} = \left|\vec{\mathrm{E}}\right|$, and $\vec{n}$ is the normal unit-vector of the curve, directed to the center. Then, the derivative of $\vec{\mathrm{E}}$ can be represented as follows:

$$\frac{\partial \vec{\mathrm{E}}}{\partial t} = -\frac{\partial \vec{\mathrm{E}}}{\partial t} \vec{n} - \mathrm{E} \frac{\partial \vec{n}}{\partial t}, \qquad (4.3.5)$$

Here, the first term has the same direction as $\vec{\mathrm{E}}$. The existence of the second term shows that at the rotation transformation of the wave an additional displacement current appears. It is not difficult to show that it has a direction tangential to the ring:

$$\frac{\partial \vec{n}}{\partial t} = -\upsilon_p \mathrm{K} \vec{\tau}\,, \qquad (4.3.6)$$

where $\vec{\tau}$ is the tangential unit-vector, $\upsilon_p \equiv c$ is the electromagnetic wave velocity, $\mathrm{K} = \frac{1}{r_p}$ is the curvature of the trajectory, and r_p is the curvature radius. Thus, the displacement current of the plane wave moving along the ring can be written in the following form:

$$\vec{j}_{dis} = -\frac{1}{4\pi}\frac{\partial \mathrm{E}}{\partial t}\vec{n} + \frac{1}{4\pi}\omega_p \mathrm{E}\cdot\vec{\tau}\,, \qquad (4.3.7)$$

where $\omega_p = \frac{m_p c^2}{\hbar} = \frac{\upsilon_p}{r_p} \equiv c\mathrm{K}$ is an angular velocity. Furthermore, here, $m_p c^2 = \varepsilon_p$ is photon energy, where m_p is some mass, corresponding to the energy ε_p.

Obviously, the terms $\vec{j}_n = \frac{1}{4\pi}\frac{\partial \mathrm{E}}{\partial t}\vec{n}$ and $\vec{j}_\tau = \frac{\omega_p}{4\pi}\mathrm{E}\cdot\vec{\tau}$ are the normal and tangent components of the displacement current of the rotated electromagnetic wave accordingly. Thus:

$$\vec{j}_{dis} = \vec{j}_n + \vec{j}_\tau\,, \qquad (4.3.8)$$

This is a remarkable fact that the currents $\vec{j}_n$ and $\vec{j}_\tau$ are always mutually perpendicular, so that we can write (4.3.8) in complex form as follows:

$$j_{dis} = j_n + i j_\tau\,, \qquad (4.3.8')$$

where $j_n = \frac{1}{4\pi}\frac{\partial \mathrm{E}}{\partial t}$ is the absolute value of the normal component of the displacement current, and

$$j_\tau = \frac{\omega_p}{4\pi}\mathrm{E} \equiv \frac{m_p c^2}{\hbar}\frac{1}{4\pi}\mathrm{E} \equiv \frac{\upsilon_p}{r_p}\frac{1}{4\pi}\mathrm{E} \equiv c\mathrm{K}\frac{1}{4\pi}\mathrm{E}\,, \qquad (4.3.9)$$

is the absolute value of the tangential component of the displacement current.

Thus, the appearance of the tangent current leads to origination of the imaginary unit in a complex form of particles' equation. So, we can assume that the appearance of the imaginary unit in the quantum mechanics is tied to the appearance of tangent currents.

3.4. A description of the rotation transformation in curvilinear space of Riemann geometry

We can consider the Maxwell-like wave equations (b) with the wave function (c) as Dirac's equation without mass. The generalization of the Dirac equation on the curvilinear (Riemann) geometry is connected to the parallel transport of the spinor in curvilinear space (Fock, 1929a,b; Fock and Ivanenko, 1929; Van der Waerden, 1929; Schroedinger, 1932; Infeld und Van der Waerden, 1933; Goenner, 2004).

In order to generalize the Dirac equation in the form of Riemann geometry, we replace the usual derivative $\partial_\mu \equiv \partial / \partial x_\mu$ (where x_μ are the co-ordinates in the 4-space) with the covariant derivative, which will be sufficient:

$$D_\mu = \partial_\mu + \Gamma_\mu\,, \qquad (4.3.10)$$

where $\mu = 0,\ 1,\ 2,\ 3$ are the summing indices, and Γ_μ is the analogue of Christoffel's symbols in the case of spinor theory, which are called Ricci symbols (or connection coefficients).

When a spinor moves along a straight line, all the symbols $\Gamma_\mu = 0$, and we have the usual derivative. However, if the spinor moves along the curvilinear trajectory, not all Γ_μ are equal to zero, and in this case an additional term appears.

Typically, the last term is not the derivative, but is equal to a product of the spinor itself with some coefficient Γ_μ, which is an increment in the spinor. It is easy to see that the tangent current j_τ corresponds to the Ricci connection coefficients (symbols) Γ_μ.

According to the general theory (Sokolov and Ivanenko, 1952), we can obtain as an additional term of equations (b) the following term: $\hat{\alpha}_\mu \Gamma_\mu = \hat{\alpha}_i p_i + i\hat{\alpha}_0 p_0$, where p_i and p_0 are real values. Since the increment in spinor Γ_μ has the form and the dimension of the energy-momentum 4-vector, it is logical to identify Γ_μ with a 4-vector of the energy-momentum of the photon's electromagnetic field:

$$\Gamma_\mu = \{\varepsilon_p, c\vec{p}_p\}, \qquad (4.3.11)$$

where ε_p and p_p are the photon's energy and momentum respectively (not the operators). In other words, we have:

$$\hat{\alpha}_\mu \Gamma_\mu = \hat{\alpha}_0 \varepsilon_p + \hat{\vec{\alpha}}\ \vec{p}_p, \qquad (4.3.12)$$

Taking into account that according to the law of conservation of energy $\hat{\alpha}_0 \varepsilon_p \mp \hat{\vec{\alpha}}\ \vec{p}_p = \pm \hat{\beta}\ m_p c^2$, we can see that the additional term contains mass of the transformed wave as a tangential current (4.3.9).

3.5. Physical sense of the rotation transformation

Let us examine what meaning the rotation transformation can have in contemporary physics.

In quantum field theroy (Ryder, 1985; see first chapter of this book), it is shown that the rotation transformation of the particle's internal symmetry (which is also taking place in our case) is equivalent to a gauge transformation, which generates the gauge fields. Recall also (Ryder, 1985) that the matrices of gauge transformation are rotation matrices in the internal space of particles.

We can easily show the identity of both transformations if we represent the energy and momentum of the intrinsic field in equation (4.3.12), using the 4-potentials A_μ, which is the gauge field within the framework of SM:

$$\hat{\alpha}_\mu \Gamma_\mu = \hat{\alpha}_0 \varepsilon_p + \hat{\vec{\alpha}}\ \vec{p}_p = e\alpha_\mu A^\mu \qquad (4.3.13)$$

Our conclusion is also confirmed by the fact that the matrices of Pauli and Gell-Mann, that are generators of the gauge transformation of groups *SU*(2) and *SU*(3) respectively, describe rotations in 2- and 3-dimensional space accordingly.

Thus, the transformation $\hat{R}$, described by the relationship (4.3.1), can be referred to as the gauge transformation, and the connection coefficients (symbols) of Ricci (or, in a general case, Christoffel's coefficients) are the gauge fields.

Thus, we can say that within the framework of NEPT the mass-free boson obtains its mass due to rotation (or gauge) transformation of particle fields. Let us note with regard to SM that in this case the role of the Higgs's boson serves the electromagnetic nuclear field. Moreover, this transformation simultaneously leads to the generation of an internal current in particle.

4.0. An equation of the massive intermediate photon

As it follows from the previous sections, some additional terms $K = \hat{\beta}\, m_p c^2$, corresponding to tangent components of the displacement current, must appear in equation (a) due to a curvilinear motion of the electromagnetic wave:

$$\left(\hat{\alpha}_o\hat{\varepsilon} - c\hat{\vec{\alpha}}\cdot\hat{\vec{p}} - K\right)\left(\hat{\alpha}_o\hat{\varepsilon} + c\hat{\vec{\alpha}}\cdot\hat{\vec{p}} + K\right)\Phi' = 0\,, \qquad (4.4.1)$$

Thus, in the case of the curvilinear transformation of the electromagnetic fields of a photon, we obtain the following Klein-Gordon-like equation with mass (Schiff, 1955), instead of equation (a):

$$\left(\hat{\varepsilon}^2 - c^2\hat{\vec{p}}^2 - m_p^2 c^4\right)\Phi' = 0, \qquad (4.4.2)$$

This is remarkable that due to a rotation transformation of the initial photon the tangential current is formed. At the same time, the current characteristics are unambiguously related to the mass of transformed photon. This mass is equal to its energy divided by a square of the speed of light. This, by the way, explains why mass divergence in electron theory is always connected with the divergence of its electrical charge.

Equation (4.4.2) is similar to the Klein-Gordon equation. However, the latter describes the **scalar** field, i.e. the massive boson with zero spin of the type of the hypothetical Higgs boson (let us also recall that Higgs's mechanism of mass generation is based on the scalar equation of Klein-Gordon). . It is not difficult to prove, using an electromagnetic form that (4.4.2) is an equation of a massive **vector** particle.

As we can see, the Φ'-function that appears after the transformation of the electromagnetic wave, and that satisfies equation (4.4.2), is not identical to the Φ-function before the transformation. The Φ-function is a classical linear electromagnetic wave field that satisfies the wave equation (a). At the same time, the Φ'-function is a non-classical curvilinear electromagnetic wave field that satisfies equation (4.4.2).

Moreover, equation (4.4.2), whose wave function is a 4×1- matrix with electromagnetic field components, *cannot be a scalar field equation.* Let us analyze the objects, which this equation describes.

It follows from the Maxwell's equations that each of the components $\mathrm{E}_x, \mathrm{E}_z, \mathrm{H}_x, \mathrm{H}_z$ of vectors of the EM wave fields $\vec{\mathrm{E}}, \vec{\mathrm{H}}$ is included into the same scalar wave equations. In the case of a linear wave, all field components are independent. So, studying each of $\vec{\mathrm{E}}, \vec{\mathrm{H}}$ vector components, we can consider the vector field as scalar. However, we cannot proceed to scalar theory after the curvilinear transformation when a tangential current appears. In fact, the components of vector $\vec{\mathrm{E}}'$ are not independent functions, as it follows from the condition (which is the Maxwell law) $\vec{\nabla}\cdot\vec{\mathrm{E}}' = \frac{4\pi}{c}\vec{c}^{\,0}\cdot\vec{j}$, where $\vec{c}^{\,o}$ is a unit vector of wave velocity.

With this regard, this equation plays a role of the Procá equation. The Procá equation can be recorded in a form, similar to equation (4.4.2)

$$\left(\hat{\varepsilon}^2 - c^2\hat{\vec{p}}^2 - m_p^2 c^4\right)A_\mu = 0, \qquad (4.4.3)$$

As it is known (Ryder, 1985), this equation is considered in SM as equation of intermediate bosons. The Procá equation is an equation for a four-dimensional vector potential, which can be used to describe a massive particle with spin equal to one.

The difference of (4.4.3) from the equation (4.4.2) lies in the fact that the free term of Procá equation is written through the 4-potential and is not gauge invariant in the case when m_p is a particle mass. In our case the mass term is expressed through the field strengths, i.e., through the wave function itself, and does not disrupt the invariance of the equations. In order to avoid difficulties of the designation, we will call the equation (4.4.2) the equation of "nonlinear photon" or the "equation of intermediate massive photon".

According to the results presented above, we need to assume that the more detailed Feynman's diagram of photoproduction of an electron-positron pair must include a massive intermediate photon. So, the diagram must have the following form (Fig. 4.4):

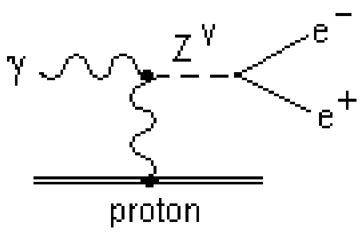

Fig. 4.4.

where we designated the nonlinear photon Z^{γ} like as an neutral intermediate massive Z^0-boson, described by the electro-weak theory within the framework of the Standard Model

5.0. Massive intermediate photon and the Z^0-boson

5.1. Appearance of the Z^0- boson in the Standard Model theory

The reaction of the electron-positron pair production is purely an electromagnetic process. In future we will examine the nonlinear representation of the electron and positron equations of Dirac and will ascertain that the weak interactions also relate to the class of electromagnetic processes. Therefore the appearance of an intermediate neutral boson in the electromagnetic process does not contradict the nonlinear theory.

In connection with this the question arises: is it possible to identify the "nonlinear photon" Z^{γ} with the neutral intermediate Z^0-boson? In the reaction Fig. 4.1 its rest mass must be equal to $2m_ec^2$, where m_e is the rest mass of electron. In other words, with these energies massive boson Z^{γ} practically coincides with electron-positron pair at the moment of their generation. It is possible to say that it is a dipole e^+e^-, comprised of these particles. This means that its lifetime is extremely small and that boson Z^{γ} cannot be experimentally registered. It is possible to say that it is in a virtual state.

As is known (Dawson, 1999; Quigg, 2007; Practicum, 2004), the same occurs for the boson Z^0. Let us examine this question in more detail, since it is directly coupling with the description of the mechanism of the generation of the masses of elementary particles in SM.

5.2. Generation and breaking of Z^0- boson

In the framework of Standard Model it is assumed that there is some additional field, which is not practically separated from the empty space. It is conventionally designated as the Higgs scalar field. It is considered that mass-free particles acquire a mass by interaction with it.

First of all it was possible to explain the generation of massive intermediate bosons and calculate their masses. It turned out that taking into account their generation, it is possible to use in the theory the same coupling constant – electromagnetic fine structure constant - for weak and electromagnetic interactions. The experimental detection of massive intermediate bosons was the triumph of Higgs's theory.

From the SM theory point of view, intermediate bosons (neutral and charged) can be generated by annihilation of fermion with anti-fermion (both leptons and quarks).

The neutral intermediate Z^0-boson was fixed first. For the first time Z^0- bosons were observed in 1983 on the accelerator SppS of CERN in the collision of beams of protons and antiprotons (Z^0- bosons were formed with the annihilation of the quark of proton with the antiquark of antiproton; see diagram Fig. 4.5).

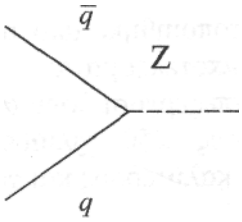

Fig. 4.5

This diagram is analogous to the diagram of the annihilation of electron-positron pair into the photon (Fig. 4.6).

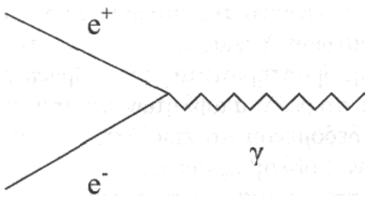

Fig. 4.6.

In this process during the specific choice of energies of the colliding electrons, the Z^0 - boson can be a real, not a virtual, particle. The diagram of generation of Z^0 - boson in the electron-positron annihilation is shown in Fig. 4.7:

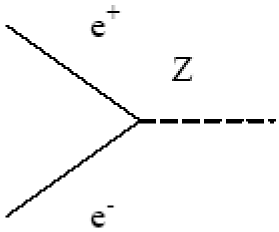

Fig.. 4.7.

On the LEP collider the energies of electron and positron beams were chosen in such way that in their sum would be equal to the mass of Z^0 - boson. In this case the cross-section of Z^0 - boson formation rises in several orders in comparison with the cross-sections of the formation of any other particles (resonance effect).

The intermediate bosons have a large mass. They are rapidly decomposed (or, equivalently, they have large widths of decay). The Z^0 - boson has many different modes (channels) of decay, and each decay mode decreases its lifetime. Formation of Z^0 - bosons can be most simply observed on the colliding beams in the reaction e^+e^- - annihilation $e^+ + e^- \to Z^0$.

In Fig. 4.8 are shown the different diagrams of the decays of intermediate bosons.

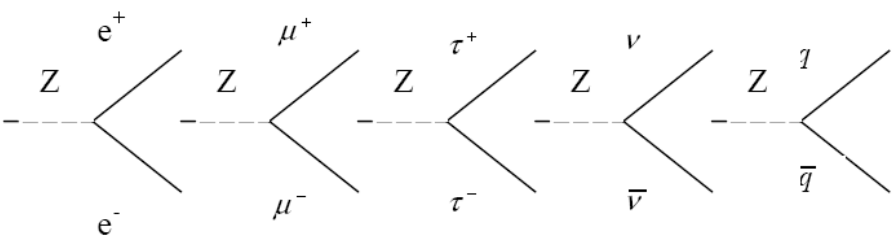

Fig. 4.8.

In electro-weak interactions the exchange is accomplished by generation and absorbance of the massive virtual particles - intermediate bosons W^+, W^- and Z^0. Using values of the masses of intermediate bosons, it is possible to give an estimation of the radius of weak interactions.

In the unified theory of electro-weak interaction the masses of W-bosons (masses of W^+ and W^- are equal) and Z^0- bosons can be computed and expressed through the Fermi constant G_F of weak interaction and Weinberg angle θ_W:

$$m_W = \frac{1}{\sin\theta_W}\frac{\pi\alpha}{\sqrt{2G_F}} = \frac{37{,}3}{\sin\theta_W}[GeV], \; m_{Z^0} = \frac{m_W}{\cos\theta_W}$$

where α =1/137 is fine structure constant. The angle of Weinberg θ_W and the boson masses m_W, m_{Z^0} are measured in independent experiments. Therefore the validity of the given relationships serves as a very substantial argument in favor of the theory of electro-weak interaction.

Mass (m_W) and width(Γ_W) of the charged W-bosons are equal to $80{,}6 \pm 0{,}4$ GeV and $2{,}25 \pm 0{,}14$ GeV respectively; mass (m_{Z^0}) and width (Γ_{Z^0}) of neutral Z^0- boson are equal to $91{,}161 \pm 0{,}031$ GeV and $2{,}534 \pm 0{,}027$ GeV.

Let us estimate, using an uncertainty principle, the maximum distance between the fermions, which are exchanged by virtual intermediate boson Z^0. For the virtual particle the energy uncertainty is equal to its rest energy: $\Delta\varepsilon \approx m_{Z^0}c^2$. Let the rest energy of Z^0-boson be approximately 91 GeV. This leads to a very small radius of weak interactions:

$$\Delta\varepsilon \cdot \Delta t \approx \hbar \rightarrow R_{Z^0} \le c\Delta t \approx \hbar c / m_{Z^0} \approx 0{,}2[GeV \cdot fm]/91[GeV] \approx 2{,}2 \cdot 10^{-16} cm$$

Using this value, it is not difficult to estimate the time of the exchange by the intermediate boson: $\Delta t \approx \frac{R_{Z^0}}{c} = 0{,}7 \cdot 10^{-26}$ s.

The obtained results explain the fact that the created by E. Fermi in the 30th years of XX century weak-interaction theory, as a theory of point interaction of four fermions, explained very well the experimental data of β-decay. This result explains also the impossibility of detecting the neutral boson in the reaction of the pair e^+e^- photoproduction, from which we began our analysis.

It remains to add that according to QED, the photon (see (Kyriakos, 2010b)) is a nonlocal particle with the characteristic size of one wavelength. This allows to conclude that the Z^γ-boson is also a nonlocal particle with the same characteristic size. (To avoid misunderstanding let us recall that within the framework of the nonlinear theory, all particles represent the field formation, which in view of the continuity of field cannot have precise boundaries. Therefore the "characteristic size" is not the particle's size, but only a value, which characterizes the energy field distribution of the particle (we will analyze this question in more detail in future).

6.0. Photon fields self-interaction as the reason for the appearance of the mass. Nonlinear equation of intermediate boson

Let us analyze in greater detail the equation of the intermediate massive photon (4.4.2) $\left(\hat{\varepsilon}^2 - c^2\hat{\vec{p}}^2 - m_p^2 c^4\right)\Phi' = 0$ and try to explain the reason for the appearance of mass m_p.

As it was shown above, due to the rotation transformation and symmetry breaking of fields of particle itself the Ricci symbols (or connection coefficients) Γ_μ appeared, which can be expressed by energy and momentum of photon by relationship (4.3.12) $\hat{\alpha}_\mu\Gamma_\mu = \hat{\alpha}_0\varepsilon_p + \hat{\vec{\alpha}}\,\vec{p}_p$. Taking into account that (in the general case) $\hat{\alpha}_0\varepsilon_p \mp \hat{\vec{\alpha}}\,\vec{p}_p = \pm\hat{\beta}\, m_p c^2$, we can obtain the energy-momentum conservation law for massive particle, expressed by means of own or internal ("in") fields of particle:

$$m_p^2 c^4 = \left(\varepsilon_{in}^2 - c^2 \vec{p}_{in}^2\right), \qquad (4.6.1)$$

The energy ε_{in} and momentum p_{in} of particle inner fields can be here expressed, using the 'inner' energy density u_{in} and 'inner' momentum density $\vec{g}_{in}$ of EM wave:

$$\varepsilon_{in} = \int_0^\tau u_{in} d\tau, \qquad (4.6.2)$$

$$\vec{p}_{in} = \int_0^\tau \vec{g}_{in} d\tau, \qquad (4.6.3)$$

assuming that the upper limit of integration for the volume τ is variable: $0 \le \tau \le \infty$.

Taking into account the EM form of Φ'- function (4.3.2), we can obtain the quantum forms of u_{in} and $\vec{g}_{in}$:

$$u_{in} = \frac{1}{8\pi}\left(\vec{E}'^2 + \vec{H}'^2\right) = \frac{1}{8\pi}\Phi'^+ \hat{\alpha}_0 \Phi', \qquad (4.6.4)$$

$$\vec{g}_{in} = \frac{1}{4\pi c}\left[\vec{E}' \times \vec{H}'\right] = -\frac{1}{8\pi c}\Phi'^+ \hat{\vec{\alpha}} \Phi', \qquad (4.6.5)$$

Substituting the expression (4.6.2) and (4.6.3) to the electron equation (4.4.2) and taking into account (4.6.4) and (4.6.5), we will obtain the *non-linear integro-differential equation of intermediate photon in both electromagnetic or quantum forms.*

An idea about the structure of nonlinear term can be obtained as a first approximation, taking into account that the solution of the photon equation is the plane wave:

$$\Phi = \Phi_0 \exp\left[i\left(\omega\, t - ky\right)\right], \qquad (4.6.6)$$

In this case we can write (4.6.2) and (4.6.3) in the next approximate form:

$$\varepsilon_{in} = u\Delta\tau = \frac{\Delta\tau}{8\pi}\Phi'^+ \hat{\alpha}_0 \Phi', \qquad (4.6.7)$$

$$\vec{p}_{in} = \vec{g}\Delta\tau = -\frac{\Delta\tau}{8\pi c}\Phi'^+ \hat{\vec{\alpha}} \Phi', \qquad (4.6.8)$$

where $\Delta\tau$ is the volume, which contain the main part of energy of the twirled photon. Then the approximate form of the equation (4.6.1) will be following:

$$m_p^2 c^4 = \frac{\Delta\tau}{8\pi}\left[\left(\Phi'^+ \hat{\alpha}_0 \Phi'\right)^2 - 4\left(\Phi'^+ \hat{\vec{\alpha}} \Phi'\right)^2\right], \qquad (4.6.9)$$

Obviously, this nonlinear term corresponds to the self-action of the "nonlinear photon" fields.

The presence of the nonlinear term of particles' field interaction means that the stability of this particle is ensured by self-interaction of particle fields.

In other words, we can assert that those conditions of the appearance of the massive particle, which we assumed in section 4.0."Electromagnetic wave theory of matter" of (Kyriakos, 2010d; p.938) as hypothesis, can actually be achieved. The mass-free photon, as a result of the transformations of its fields in the strong electromagnetic field of proton, begins to move (rotate) in a limited volume of space. Its relative stability is ensured by self-interaction of photon fields. Conditionally speaking, the "nonlinear photon" creates quasi-walls for itself, which act similar to the waveguide or resonator walls. When observed outside the volume, inside which photon moves, this photon looks as massive particle in rest.

6.2. Comparison of the description of intermediate boson in the nonlinear theory and in the Standard Model

Let us compare the results, obtained above within the framework of nonlinear quantum field theory, with those we have in the theory of Standard Model (CM).

In SM the additional scalar field of Higgs is introduced, in order to generate of the mass of intermediate bosons. The passage from it to the 4-vector equation of Procá for the massive particles requires the use of complex mathematical procedures on the basis of gauge transformation. In the proposed nonlinear theory the real vector EM field of photon is used, which in the general case four-component is (but it is not 4-vector !). Therefore, the passage to the equation of massive intermediate photon (analog of Procá equation) requires nothing, except the transformation of rotation.

As we noted (see (Kyriakos, 2010c)), gauge transformation is mathematically the transformation of rotation. The difference consists in the fact that in NTEP the transformation of rotation has the direct physical sense of transformation of fields. At the same time, in the SM the gauge transformation is a mathematical procedure. For this reason in SM the passage from one Lagrangian to another occurs on the basis of special assumptions and prescriptions.

Another serious difference lies in the fact that in SM the intermediate bosons remains mass-free after gauge transformation in order not to disrupt the renormalization. One of the reasons for this is the fact that in SM the vector potential is used as the wave function of photon and massive bosons, rather than the strength of EM fields. Therefore, Higgs's mechanism is required for the particles to obtain masses. In the nonlinear theory the mass of intermediate photon appears as kinetic photon energy, “stopped” as a result of self-interaction of fields of the photon (see section 4.0.“Electromagnetic wave theory of matter” of (Kyriakos, 2010d; p.938).

As addition let us examine briefly some correspondences of mathematical description of mass production in both theories.

In the framework of SM (Dawson, 1999; Quigg, 2007; Kyriakos, 2010d) the Lagrangian of the interaction and propagation of the scalar field is

$$L_{scalar} = \left(D^{\mu}\phi\right)^{+}\left(D_{\mu}\phi\right) - V\left(\phi^{+}\phi\right), \qquad (4.6.10)$$

where D_{μ} the gauge-covariant derivative is. The potential of Higgs interaction has the form

$$V\left(\phi^{+}\phi\right) = \mu^{2}\left(\phi^{+}\phi\right) + |\lambda|\left(\phi^{+}\phi\right)^{2}, \qquad (4.6.11)$$

In NTEP the Lagrangian of interaction of photon with proton we can write down in form:

$$L = \Phi^{+}\left(\hat{\alpha}_{o}\hat{\varepsilon} - c\hat{\vec{\alpha}}\cdot\hat{\vec{p}}\right)\left(\hat{\alpha}_{o}\hat{\varepsilon} + c\hat{\vec{\alpha}}\cdot\hat{\vec{p}}\right)\Phi + L\left(\Phi, N\left(\vec{r},t\right)\right) + L\left(N\left(\vec{r},t\right)\right), \quad (4.6.12)$$

where Φ is photon wave function (c); $N = N\left(\vec{r},t\right)$ is the nuclear field, which detail description we don't know in the area, closed to nucleus themselves; the term $L\left(N\left(\vec{r},t\right)\right)$ is the nucleus Lagrangian in conditional form and $L\left(\Phi, N\left(\vec{r},t\right)\right)$ is the photon-nucleus interaction Lagrangian.

After a photon transformation into the massive boson, the Lagrangian of the vector massive boson of equation (4.4.2) will be the following:

$$L = \Phi'^{+}\left(\hat{\alpha}_{o}\hat{\varepsilon} - c\hat{\vec{\alpha}}\cdot\hat{\vec{p}} + m_{p}c^{2}\right)\left(\hat{\alpha}_{o}\hat{\varepsilon} + c\hat{\vec{\alpha}}\cdot\hat{\vec{p}} - m_{p}c^{2}\right)\Phi' + L\left(N\left(\vec{r},t\right)\right), \quad (4.6.13)$$

Without the Lagrangian of nucleus (which doesn’t work now), equation (4.6.13) can be recorded in the form:

$$L = D_{\mu}\Phi'^{+} D^{\mu}\Phi' = \partial_{\mu}\Phi'^{+}\partial^{\mu}\Phi' - \Phi'^{+} m_{p}^{2}c^{4}\Phi', \qquad (4.6.14)$$

where the term

$$\Phi' m_{p}^{2}c^{4}\Phi' = \frac{\Delta\tau}{8\pi}\Phi'\left[\left(\Phi'^{+}\hat{\alpha}_{0}\Phi'\right)^{2} - 4\left(\Phi'^{+}\hat{\vec{\alpha}}\Phi'\right)^{2}\right]\Phi', \quad (4.6.15)$$

describes in the nonlinear theory the energy of self-interaction, which directly contains the mass of intermediate boson.

It is not difficult to see that the expression (4.6.15) has a similarity with Higgs's potential (4.6.11). We did not investigate in detail this parallelism, because the analysis, carried out above, indicates the possibility of describing of the particle mass production by means of intermediate boson, but without the presence of Higgs's boson.

In the following chapters we will examine the question of the generation of mass of leptons - electron and neutrino - on the basis of the presented above theory of particle fields' self-interaction.

Bibliography

Dawson, S. (1999). Introduction to Electroweak Symmetry Breaking. http://arxiv.org/abs/hep-ph/9901280

Eisenhart, L. P. (1960). *A Treatise on the Differential Geometry of Curves and Surfaces.* New York: Dover.

Fock, V. (1929a). "Geometrisierung der Diracschen Theorie des Electrons", *Z. Phys*. 57 (1929) 261-277;

Fock, V. (1929b) "L'Equation d'Onde de Dirac et la Geometrie de Riemann", *J.Phys. Rad.* 10 392-405;

Fock, V. and Ivanenko, D. (1929). C.R., *Phys. Zs*. 30, 648

Goenner, H. F. M. (2004). Living Reviews Relativity, 7, Online Article: http://www.livingreviews.org/lrr-2004-2)

Infeld L. und van der Waerden B. L., (1933). Berliner Berich., S. 380.

Kyriakos, A.G. (2009) The Nonlinear Quantum Field Theory as a Generalization of Standard Model http://www.amazon.com/Nonlinear-Generalization-Standard-Geometrical-Approach/dp/0980966744

Kyriakos A.G. (2010a) Theory of Elementary Particles 1. Choice of Axiomatics and Mathematical Apparatus of Theory. http://vixra.org/abs/1005.0019

Kyriakos, A.G. (2010b). Nonlinear Theory of Elementary Particles 2. The Photon Theory. http://vixra.org/abs/1006.0029

Kyriakos A.G. (2010c). Comparison of the algorithmic and axiomatic approaches to the construction of quantum field theory http://vixra.org/abs/1003.0169

Kyriakos, A.G. (2010d). Nonlinear Theory of Elementary Particles: III. The Mass Origin Theories. http://prespacetime.com/index.php/pst/article/viewFile/83/75

Practicum, (2004). Practice. Particles and atomic nuclei. (in Russian). , Moscow, Moscow State Univercity, 2004. http://nuclphys.sinp.msu.ru/p/zad_09.pdf

Quigg, Chris. (2007) Spontaneous symmetry breaking as a basis of particle mass. Rep. Prog. Phys. 70 (2007) 1019-1053. (http://iopscience.iop.org/0034-4885/70/7/R01)

Ryder, L.H. (1985) *Quantum field theory*, 2nd ed., Cambridge Univ. Press., Cambridge, UK.

Schroedinger E. (1932). Berliner Berich., S.105.

Sokolov, A. and Ivanenko, D. (1952) *The quantum field theory* (in Russian), Moscow-Leningrad.

Van der Waerden, B. L. (1929) „Spinoranalyse", *Gott. Nachr*. 100-109.