Chapter 11. On the structure and theory of hadrons

1.0. Introduction. Short review of QCD

Hadrons are particles made from quarks and gluons, bound together by their strong interactions. Hadrons have no net strong charge (or color charge) but they do have residual strong interactions due to their color-charged substructure. The theory, which describes hadrons, is called quantum chromodynamics (QCD).

1.1. QCD as the Yang-Mills theory. Generally information

Quantum chromodynamics (QCD) (The Columbia Encyclopedia, 2008) is quantum field theory that describes the properties of the strong interactions between quarks and between protons and neutrons in the framework of quantum field theory .

Quarks possess a distinctive property called color that governs their binding together to form other elementary particles . Color is of three varieties, analogous to electric charge in charged particles, arbitrarily designated as red, blue, and yellow, and - analogous to positive and negative charges - three anticolor varieties. Just as positively and negatively charged particles form electrically neutral atoms, colored quarks form particles without color.

Quarks interact by emitting and absorbing massless particles called gluons , each of which carries a color-anticolor pair. Eight kinds of gluons are required to transmit the strong force between quarks, e.g., a blue quark might interact with a yellow quark by exchanging a blue-antiyellow gluon.

Quantum chromodynamics is the study of the SU(3) Yang–Mills theory, which is a quantum field theory of a special kind called a non-abelian gauge theory. It is an important part of the Standard Model of particle physics (Okun, 1982; 1988; Pich, 2000; Ryder, 1985).

The dynamics of the quarks and gluons are controlled by the quantum chromodynamics Lagrangians. The full QCD Lagrangian is

$$L_{QCD} = L_q + L_G$$

where $L_q = \sum_{i,\alpha} \psi^{+}{}_{i,a} \left(\alpha_\mu \hat{D}_\mu + m_i \right) \psi_{i,a}$ is the Lagrangian of quarks, $L_G = -\frac{1}{4} G^a_{\mu\nu} G^{\nu\mu}_a$, ($a = 1,2,...,8$) is the Lagrangian of gluons, so that

$$L_{QCD} = \sum_{i,\alpha} \psi^{+}{}_{i,a} \left(\alpha_\mu \hat{D}_\mu + m_i \right) \psi_{i,a} - \frac{1}{4} G^a_{\mu\nu} G^{\nu\mu}_a$$

where ψ_{ia} is the quark bispinor, a dynamical function of space-time, in the fundamental representation of the SU(3) gauge group; i is a particle flavour index, a is a particle colour index, m_i is a mass of i-quark; $G_\mu = G^a_\mu \lambda_a / 2$, $(a = 1,2,...,8)$ are the vector potentials of eight gluon fields, also a dynamical function of space-time, in the adjoint representation of the SU(3) gauge group; λ_a are eight Gell-Mann matrices. $D_\mu = \partial_\mu - igG_\mu$ is the covariant derivative in QCD (now this is also a matrix). The α_μ are Dirac matrices connecting the spinor representation to the vector representation of the Lorentz group. The Gell-Mann matrices provide one such representation for the generators.

The symbol $G^a_{\mu\nu}$ represents the gauge invariant gluonic field strength tensor, analogous to the electromagnetic field strength tensor, $F^{\mu\nu}$, in electrodynamics. It is given by $G^a_{\mu\nu} = \partial_\mu G^a_\nu - \partial_\nu G^a_\mu - ig\left[G_\mu G_\nu - G_\nu G_\mu\right]$, where the constant g is the coupling constants of the theory.

1.2. Yang-Mills equation in electromagnetic representation

QCD is nearly identical in mathematical structure to quantum electrodynamics (QED) and to the unified theory of weak and electromagnetic interactions. According with Y. Nambu: “The theory of the Yang-Mills fields is the generalization of the Maxwell theory or non-Abelian gauge fields; its equations are nonlinear; in contrast to this, the equations of Maxwell are linear, in other words, Abelian”.

The simplest generalization (Ryder, 1985) is to SU(2). This group, as well as the more complicated ones which are considered in physics, is non-Abelian, so what we are studying is the subject of non-Abelian gauge fields.

The problem is that we are performing a different 'iso-rotation' at each point in space, which we may express by saying that the 'axes' in isospace are oriented differently at each point.

Let us examine the rotations of a certain field vector $\vec{F}$ about the 3 axis in the internal symmetry space through an infinitely small angle $\vec{\varphi}$. The meaning of this angle is that $|\vec{\varphi}|$ is the angle of rotation, and $\vec{\varphi}/|\vec{\varphi}|$ is the axis of rotation. Then transition from the initial position of the vector to the final one will be determined by the transformation:

$$\vec{F} \to \vec{F}' = \vec{F} - \vec{\varphi} \times \vec{F}, \qquad (11.1.1)$$

We have then a gauge transformation of the first kind, and is, of course, effectively three equations.

$$\delta\vec{F} = \vec{F}' - \vec{F} = -\vec{\varphi} \times \vec{F}, \qquad (11.1.2)$$

In contrast to electrodynamics the present case is more complicated, however, and this is directly traceable to the fact that in the present case the rotations form the group SO(3) which is non-Abelian. Its non-Abelian nature is responsible for that fact that $\vec{a} \times \vec{b} = -\vec{b} \times \vec{a}$: the vector product is not commutative. It will be seen below how this complicates matters. These complications have direct physical consequences.

First note that (11.1.2) is an instruction to perform a rotation in the internal space of $\vec{F}$ through the same angle $\vec{\varphi}$ at all points in space-time. We modify this to the more reasonable demand that $\vec{\varphi}$ depends on x^μ $\vec{\varphi} = \vec{\varphi}(x^\mu)$ (i.e. that the same relationships are also valid in the four-dimensional space). In this case $\partial_\mu \vec{F} \to \partial_\mu \vec{F}' = \partial_\mu \vec{F} - \partial_\mu \vec{\varphi} \times \vec{F} - \vec{\varphi} \times \partial_\mu \vec{F}$, or

$$\delta(\partial_\mu \vec{F}) = \partial_\mu \vec{F}' - \partial_\mu \vec{F} = -\partial_\mu \vec{\varphi} \times \vec{F} - \vec{\varphi} \times \partial_\mu \vec{F}, \qquad (11.1.3)$$

Expressed in words, $\partial_\mu \vec{F}$ does not transform covariantly, like $\vec{F}$ does. We must construct a 'covariant derivative'. This will involve introducing a gauge potential analogous to electromagnetic potential A_μ. We then write the covariant derivative of the vector $\vec{F}$ as

$$D_\mu \vec{F} = \partial_\mu \vec{F} + g\vec{W}_\mu \times \vec{F}, \qquad (11.1.4)$$

where $\vec{W}_\mu$ is the gauge potential analogous to A_μ. Note that it is a vector in the internal space, whereas A_μ only had one component; g is a coupling constant, analogous to electric charge *e*. Analogous to the case of A_μ we can write for $\vec{W}_\mu$: $\vec{W}_\mu \to \vec{W}_\mu - \vec{\varphi}\times\vec{W}_\mu + \frac{1}{g}\partial_\mu\vec{\varphi}$, or

$$\delta\vec{W}_\mu = -\vec{\varphi}\times\vec{W}_\mu + \frac{1}{g}\partial_\mu\vec{\varphi}, \tag{11.1.5}$$

Let us call the analogue of the field strength $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$ as $\vec{W}_{\mu\nu}$. Unlike $F_{\mu\nu}$, which is a scalar under SO(2), $\vec{W}_{\mu\nu}$ will be a vector under SO(3), and so will transform like $\vec{F}$ itself: $\delta\left(\vec{W}_{\mu\nu}\right) = -\vec{\varphi}\times\vec{W}_{\mu\nu}$. So if we define

$$\vec{W}_{\mu\nu} = \partial_\mu\vec{W}_\nu - \partial_\nu\vec{W}_\mu + g\vec{W}_\mu\times\vec{W}_\nu, \tag{11.1.6}$$

The field strength $\vec{W}_{\mu\nu}$ is a vector; so $\vec{W}_{\mu\nu}\cdot\vec{W}^{\mu\nu}$ is a scalar and will appear in the Lagrangian

$$L = (D_\mu\vec{F})\cdot(D^\mu\vec{F}) - m^2\vec{F}\cdot\vec{F} - \frac{1}{4}\vec{W}_{\mu\nu}\cdot W^{\mu\nu}, \tag{11.1.7}$$

The equations of motion are obtained by functional variation of this Lagrangian in the usual way from the Euler-Lagrange equation

$$D^\nu\vec{W}_{\mu\nu} = g(D_\mu\vec{F})\times\vec{F} \equiv g\vec{J}_\mu, \tag{11.1.8}$$

This equation is analogous to Maxwell's equation for the 4-current, so that $\vec{W}_{\mu\nu}$ is the 'isospin' gauge field, $\vec{J}_\mu$ is the source or 'matter' term, and instead of ordinary derivatives there are covariant ones. Whereas Maxwell's equations are linear in A_μ, however, this equation is non-linear in $\vec{W}_\mu$. In the absence of matter Maxwell's equation indicates that there is no source term for the electromagnetic field; on the contrary, the non-Abelian gauge-field equation indicates that the field $\vec{W}_{\mu\nu}$ acts as a source for itself.

Not everything is different when we go to the non-Abelian case, however. One thing that is the same is that the 'isospin' field $\vec{W}_{\mu\nu}$, **must be massless,** just like the electromagnetic field. The reason is the same: to account for a field with mass *m*, an extra term

$$L_m = m^2\vec{W}_\mu\cdot\vec{W}^\mu, \tag{11.1.9}$$

must be added to the Lagrangian. The equation of motion (11.1.8) is then changed to

$$D^\nu\vec{W}_{\mu\nu} = g\vec{J}_\mu + m^2\vec{W}_\mu, \tag{11.1.10}$$

The term (11.1.9), however, is clearly not gauge invariant, so, as before, we see that gauge invariance implies zero mass for the gauge field.

The non-Abelian generalisation of equations, which are analogous to the homogeneous Maxwell equations $\partial_\lambda F_{\mu\nu} + \partial_\mu F_{\nu\lambda} + \partial_\nu F_{\lambda\mu} = 0$, is

$$D_\lambda\vec{W}_{\mu\nu} + D_\mu W_{\nu\lambda} + D_\nu W_{\lambda\mu} = 0, \tag{11.1.11}$$

Let us note that the procedure of obtaining Yang- Mills equation, described above, cannot be considered as a sequential derivation of the equation. Firstly, because: 'to account for a field with mass m, an extra term $L_m = m^2\vec{W}_\mu \cdot \vec{W}^\mu$ must be added to the Lagrangian'. With the sequential dervation of the equation this term must be obtained automatically. Secondly, this introduction of mass leads to a significant complication of the theory. In particular, 'the 'isospin' field $\vec{W}_{\mu\nu}$ **must be massless,** just like the electromagnetic field'.

The reason of this, as we have already noted, is the use of potential instead of the field strength. Further we will ascertain that within the framework of NTEP these difficulties do not appear.

1.3. A three Dirac spinor model for description of the proton

Attempts to derive the Yang- Mills equation on the basis of his similarity to Dirac's equation were undertaken. An important feature of this enterprise is the treatment of the structure of composite systems consisting of two or three quarks. The general form of the two-spinor wave function was given many years ago by Goldstein (Goldstein, 1953), and these forms have been widely used for the quark-antiquark mesonic system.

For example, in the paper (Henriques, et all., **1975**), authors consider the relativistic spin structure of the three-quark baryonic system. The general form of the three-spinor wave function was developed as a natural extension of the two-spinor system, but the situation is here considerably complicated by the necessity for maintaining the symmetry properties of the wave function under quark interchange.

A relativistic spin ½ -particle is described by a four-component Dirac spinor, whether the particle is free or bound. In the single particle case, this spinor is the solution of the Dirac equation with an appropriate potential. When two or more spin ½-particles mutually interact to form a composite system, the general wave function has the form of a product of the Dirac spinors for the individual constituents.

Goldstein (Goldstein, 1953) has shown that for the two-fermion case, it is convenient to rewrite this direct product of spinors as an outer product, and expand the resulting 4 x 4 matrix representation in terms of the complete set of 16 Dirac matrices. In this representation, operators acting on the second quark are represented by postmatrix multiplication by the transpose of the operator. The two-fermion wave function is written $\psi_{\alpha\beta} = \psi_\alpha \psi_\beta$, where ψ_α is the individual quark spinor.

For the three-quark system authos develop a similar generalized matrix representation for the direct product of three spinors.

The idea of the wave function of the hadrons in the form of the product of spinor functions, proposed above, was not very popular. Nevertheless, similarity and relationship of the Yang- Mills equation and the Dirac equation follow from NTEP and, as we will show below, can be assumed as the basis of derivation of Yang- Mills equation.

1.4. The difficulties and peculiarities of hadron theory

1.4.1. *Asymptotic freedom*

Asymptotic freedom is a feature of QCD. The theory of asymptotic freedom states that the interaction between quarks reduces as the distance between them reduces (and hence energy increases), and tends to zero as the distance between them reduces to zero. Conversely, the interaction between them increases as they are separated by larger distances (and hence lower energies).

If a theory requires the presence of Higgs Boson, asymptotic freedom is destroyed. Hence, the electroweak theory is not asymptotically free (or, the electromagnetic and weak forces are asymptotically not free). Also the strong nuclear force obeys the theory of asymptotic freedom.

Another result, originating from the theory of asymptotic freedom, is the quark confinement hypothesis.

1.4.2. *Quark confinement*

Recalling the implications of the asymptotic freedom, we ultimately see that the force between the two quarks (due to a "colour charge"), increases at lower energies as they are separated more and more from one another. This leads to the idea that free quarks are never seen in isolation.

Color confinement is the physical principle explaining the non-observation of color charged particles like free quarks. Color confinement often simply called confinement. The reasons for quark confinement are somewhat complicated; no analytic proof exists that QCD should be confining, but intuitively, confinement is due to the force-carrying gluons having color charge.

1.4.3. *Proton spin crisis*

The proton has a definite, measurable mass, electric charge, and spin, and its lifetime is at least as long as the universe is old. On the other hand, the proton has a complicated internal structure. It is composed of different types of quarks held together by the strong force, which is mediated by gluons.

Because the proton has a well-defined spin of ½ , the spins of the individual bits and pieces inside it should add up to exactly that value. Each quark has a spin of ½ , and each gluon a spin of 1. Initially, theorists made the naive assumption that two of a proton's quarks align like tops spinning in opposite directions, so their net spin is zero, while the third quark has an uncompensated spin of ½ . This configuration leads to an overall spin of ½ for the proton, provided that the spins of the gluons somehow cancel out.

The first news that the simple quark spin model was inadequate came from the 1988 experiment of European Muon Collaboration (EMC) at the European Laboratory for Particle Physics (CERN) in Geneva. The finding experimental evidence suggests that very little of the proton's spin comes from the spin of the quarks thought to make up the proton (Science News: 4/8/89, p. 215). This apparent paradox was called the *proton spin crisis*.

One check on the experimental results was to perform a similar experiment using neutrons instead of protons. That experiment was done at the Stanford Linear Accelerator Center (SLAC). The results indicated that a neutron's quarks carry roughly 50 percent of its spin (Science News: 9/18/93, p. 191).

Complicating the picture, the number of quarks within the particle can actually fluctuate rapidly with the continuous creation and annihilation of quark-antiquark pairs. In other words, the three constituent quarks speed about within a foaming sea of virtual particles produced by short-lived quantum fluctuations, during which a gluon can momentarily split itself into a quark-antiquark pair.

Most physicists suspected that much of the proton's spin comes from its gluons. In the paper (Balitsky and Xiangdong, 1997) authors calculate that gluons contribute at least half of the proton spin. However, there is scant experimental evidence concerning the gluon's effect on the proton's spin..

A new experiment in 2002 began at CERN, called COMPASS, which stands for Common Muon and Proton Apparatus for Structure and Spectroscopy. It expect to probe the gluon content of the proton by firing high-energy muons at polarized targets and looking for ejected mesons containing the charm quark. It turned out that the contribution of gluons to the spin of proton is less than the contribution of quarks!

Spin crisis is not overcome until now. The scientists attempted to represent the spin of proton by the sum of contributions from quarks, gluons and their orbital angular momentum. Thus, now the basic task is the measurement of the contribution to the spin of proton from the orbital angular momentum of all its components. A series of experiments on the study of the three-dimensional structure of proton will be carried out for this. The COMPASS-II is planned to begin these experiments in 2014.

When these and several related experiments are completed, physicists would have the data to tell of how the proton's constituents give it its spin.

1.4.4. *Hadron mass problem*

The hadrons are made up of two (meson) or three (barion) quarks. The lighter barion are proton and neutron. The proton has a mass in energy units of 938.256 MeV while the neutron is 939.550 MeV. The proton and neutron are made from lights quarks. A proton is made up of two u-quarks and one d-quark while a neutron is made from two d-quarks and one u-quark. The lighter particles of meson called Pions that are made from pairs of u- and d-quarks. Pions have masses of 139.6 MeV for Pi^+ or Pi^- and 134.975 MeV for the Pi^0 (neutral).

If we could produce free quarks we could simply measure their masses just like we have measured the proton, the electron, the neutron and other particles to very high accuracy. But free quarks have not been found so we must derive their properties by a mix of theory and experiments.

One of the reasons that we can't just us simple algebra to get the quark masses is that the quarks are bound tightly together. That is, the composite particle mass is less than the separate quarks would. If we had a theory that could predict the binding energy of the common particles then we could calculate the quark masses correctly. A possible mechanism that extends the Standard Model and accounts for the origin of the masses of the quarks is called the Higgs Mechanism. But until now it could not be confirmed by experiments.

1) In the framework of Standard Model (Wikipedia. Quark's Masses**)** two terms are used in referring to a quark's mass: *current quark mass* refers to the mass of a quark by itself, while *constituent quark mass* refers to the current quark mass plus the mass of the gluon particle field surrounding the quark. These masses typically have very different values. Most of a hadron's mass comes from the gluons that bind the constituent quarks together, rather than from the quarks themselves. While gluons are inherently massless, they possess energy - more specifically, *quantum chromodynamics binding energy* - and it is this that contributes so greatly to the overall mass of the hadron. For example, a proton has a mass of approximately 938 MeV/c^2, of which the rest mass of its three valence quarks only contributes about 11 MeV/c^2; much of the remainder can be attributed to the gluons' binding energy.

The current quark mass is a logical consequence of the mathematical formalism of the QFT, thus it is from a not descriptive origin. The current quark mass is a parameter to compute sufficiently small color charges. The current quark mass is also called the mass of the '*bare*' *quarks.* The mass of the *current quark* is reduced by the term of the *constituent quark covering mass*. Therefore the current quark masses of the light current quarks are much smaller than the constituent quark masses.

At present large efforts are applied in order to calculate the mass of the hadrons on the basis of chiral symmetry breakdown approach. But this approach has the serious limitations

2) Chiral symmetry breakdown approach

The QCD Lagrangian (Ioffe, 2006; Manohar and Sachrajda, 2010) has a chiral symmetry in the limit that the quark masses vanish. This symmetry is spontaneously broken by dynamical chiral symmetry breaking, and explicitly broken by the quark masses. The nonperturbative scale of dynamical chiral symmetry breaking, Λχ, is around 1GeV. It is conventional to call quarks heavy if *m* > Λχ, so that explicit chiral symmetry breaking dominates (c, b, and t quarks are heavy), and light if *m* < Λχ, so that spontaneous chiral symmetry breaking dominates (u, d and s quarks are light).

The origin of the mass of the matter will be clarified when the mechanism of chiral symmetry breaking in QCD is established.

Two approaches exist, which are close to the approach, which is used in NTEP.

3) Approach on the basis of nonlinear Heisenberg theory

Within the framework of the Heisenberg variant of the unified nonlinear spinor theory of elementary particles an attempt is made to calculate the mass of the fundamental fermion (proton) **(**Naumov, 1965**)**. The guiding principle is here the notion of the existence of a relation between the helicity properties of particles and their masses. In this case it proves necessary to take into account the possibility of degeneracy of the vacuum of the system of interacting fields in certain quantum numbers. A program is outlined for constructing a realistic scheme of elementary particles to include their isotropic and "strange" properties. The possibility of eliminating divergences from the nonlinear theory, while preserving its applicability, by means of a somewhat modified perturbation theory is briefly discussed.

4) Approach on the basis of electromagnetic theory and QED

Motivated by the need to understand hadron masses, in the article (Xiangdong and Wei, 1998**).** the autors return to an old problem - the composition of the electron mass. They showed that in the unrenormalized representation of electron, the vacuum subtraction plays an important role in understanding basic sources of the electron mass.

From the formal side of quantum field theory, one can see a number of similarities between the proton and electron. Both of them are elementary excitations of the field theoretical vacua. In the case of the proton, they are the bare or renormalized quarks and gluons, while in the case of the electron, they are the bare or renormalized electrons and photons. Additionally, both the electron and proton are stable, and have lower energy level in their families.

Hence, it is possible to hope to learn some field theoretical aspects of the proton through studying the simpler electron. In this case the understanding of the internal structure of hadrons, the proton in particular, is perhaps one of the most important problem in theoretical physics.

As authors note, a consistent formulation of the electron mass problem became possible only after Dirac proposed his positron theory – the precursor of QED. According to modern interpretation, the basic building blocks in the theory are the *bare electrons and photons*, which are defined when the electromagnetic interactions were turned off. Clearly then, they are not physically observable particles. The bare electron does have a mass (the bare mass), but question is if it has the electromagnetic origin.

We note that question about electromagnetic mass examined R. Feynman in his lectures (Feynman et al., 1964) in chapter 28. "Electromagnetic mass", where Feyman concludes : "So we come back again to the original idea of Lorentz - may be all the mass of an electron is purely electromagnetic, maybe the whole 0.511 MeV is due to electrodynamics. Is it or isn't it? We haven't got a theory, so we cannot say".

Note that since in the NTEP it is shown that the electron mass is only the electromagnetic mass, the approach of the authors (Xiangdong and Wei, 1998) is completely consistent.

When the electromagnetic interaction is turned on, the QED vacuum becomes nontrivial and the vacuum excitations produce a physical particle whose quantum numbers are the same as those of the bare electron. Pictorially this physical electron contains a bare electron in the QED vacuum plus the vacuum polarizations. Because of the small electromagnetic coupling, the structure of the physical electron can be calculated perturbatively using the bare degrees of freedom. Hence the physical mass of the electron can be "explained" in terms of the bare electron mass plus the contributions from the electromagnetic interactions. In light of the fact that the physical mass is observable while the bare mass is not, such an explanation is not practically interesting and is usually ignored in modern textbooks. However, as we shall advocate in this paper, the explanation may help to understand some interesting aspects of the proton bound state about which we know very little in QCD.

In other papers (Xiangdong, 1994; Xiangdong, 2006)**)** author shows that an insight on the mass structure of the nucleon can be produced within QCD with the help of the deep-inelastic momentum sum rule and the trace anomaly. The result is a separation of the nucleon mass into the contributions from the quark, antiquark, gluon kinetic and potential energies, the quark masses, the gluon trace anomaly. Numerically, the only large uncertainty is the size of matrix element $\langle P \mid m_s \bar{s}s \mid P \rangle$, the strange scalar charge of the nucleon. Some implications of this break-up of the masses are obtained. The complete result of the mass decomposition at the scale of $\mu^2 = 1\,\text{GeV}^2$, together with the two numerical estimates, is shown Table 1.

Table 1. A decomposition of the nucleon mass into different contributions.

mass type	H_i	M_i	$m_s \to 0$(MeV)	$m_s \to \infty$(MeV)
quark energy	$\bar{\psi}(-i\mathbf{D}\cdot\alpha)\psi$	$3(a-b)/4$	270	300
quark mass	$\bar{\psi}m\psi$	b	160	110
gluon energy	$\frac{1}{2}(\mathbf{E}^2+\mathbf{B}^2)$	$3(1-a)/4$	320	320
trace anomaly	$\frac{9\alpha_s}{16\pi}(\mathbf{E}^2-\mathbf{B}^2)$	$(1-b)/4$	190	210
Total			**940**	**940**

1.4. 5. Hadron properties of photon and electron

During the recent decades high-energy photon interactions are discussed (Bauer et al., 1978) in terms of the hadronic structure of the photon. Experiments demonstrate and yield information about this hadronic structure.

The concept of the photon originated in the first years of quantum mechanics, and the study of electromagnetic interactions with matter has played a prominent role throughout the history of quantum theory. At first, the photon was regarded as structureless, and the theory was very successful in predicting various spectral lines and their intensities and in understanding other processes such as the atomic photoeffect.

Pair production occurs because of the basic interactions $\gamma \leftrightarrow e^- + e^+$ required by relativistic quantum theory. These interactions are between "bare" states described by a "free Hamiltonian". Physical particle states, however, are eigenstates of the complete Hamiltonian. Therefore, a physical particle state contains not only the corresponding bare particle state, but also contributions from all bare states coupled to it by the interaction.

Accordingly, with the above interaction, the physical photon has an electron-positron pair constituent. It is possible to think of pair production as arising through the scattering of this constituent by the Coulomb potential, permitting the pair to actually materialize, provided that the energy available is sufficiently high, i.e., $>2m_ec^2$. At low energies ($<<2m_ec^2$), the virtual e^-e^+ pair does not manifest itself in a very pronounced way, although it does of course play an important role in refined quantum-electrodynamic effects. This illustrates the point that *at different energy scales, different aspects of the underlying dynamics become visible.*

When the first experiments on photoproduction of pions and electron scattering from nucleons were carried out, the photon (real or virtual) was for purposes of hadronic interactions again regarded as structureless. Within the last years, there has been a growing awareness that this is too simple a view, and that in reality the photon has an internal structure which is very similar to that of hadrons. Special attention is paid to diffractive processes such as the photoproduction of *vector mesons* and to photon shadowing effects on nuclei.

The ability of interacting high-energy photons to assume a broad range of masses (Murphy and Yount, 1971) is crucial in understanding the hadronic character of light since it allows interacting photons to take on the masses and attributes of vector mesons. The uncharged members of a certain class of particles called vector mesons have the same quantum numbers as the photon. However, even in their free, real state they are not massless, and they interact strongly with other mesons and with nucleons (i.e., they are hadrons).

In 1 GeV range three vector mesons are presently known: the rho, the omega, and the phi. The charge of the rho can be positive, negative, or zero, while the omega and phi exist only with zero charge. (Photons, being neutral, couple strongly only to neutral vector mesons.)

In this energy range the quark model predicts that the photon should behave as if it were '75% rho, 8% omega, and 17% phi. This really means, of course, that in a large sample of interactions the photon will behave as a rho in 75% of the interactions, as an omega in 8%, and as a phi in 17%.

Mathematically for obtaining this result the standard expansion of unity into the theories of the linear operators is used:

$$1 = |\mathrm{H}(x)\rangle\langle\mathrm{H}(x)|$$

where $|\mathrm{H}(x)\rangle$ are hadron wave functions, which form a complete basis. In the general case unit is a unit matrix. A unit, (unit matrix) is obtained regarding the complete basis. In order to obtain expansion, it is necessary to act by this unit on the wave function of the photon $|\Phi(x)\rangle$:

$$|\Phi(x)\rangle = 1\cdot|\Phi(x)\rangle = |\mathrm{H}(x)\rangle\langle\mathrm{H}(x)||\Phi(x)\rangle = c(x,y)|\mathrm{H}(x)\rangle$$

and $c(x, y)$ are assumed as the coefficients of the expansion of photon into hadrons. In this case it is considered that all known vector mesons form a complete basis. In the expansion of photon the ground states play a main role, and the contributions of excited states are small.

The most elegant method for studying the vector-meson composition of the photon is clearly the colliding electron and positron beams in which the production of the vector mesons is well isolated from other, potentially confusing, interactions. The reaction $e^+e^- \rightarrow e^+e^-p\bar{p}$ is studied (The L3 Collaboration, 2003) with the L3 detector at LEP. Electron-positron colliders are a suitable place for the study of two-photon interactions via the process $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-X$, where γ^* denotes a virtual photon.

The knowledge of the structure of the photon is presented in the paper (Nisius, 2000) with emphasis on measurements of the photon structure obtained from deep inelastic electron-photon scattering at ee^+-collider.

2.0. The hadron theory: target setting

According to the axiomatics, accepted in NTEP, the reason for the generation of massive elementary particles is the rotatory transformation of mass-free electromagnetic wave fields. Moreover, within the framework of NTEP it is shown that all characteristics of particles must appear uniformly from the transformations of electromagnetic wave fields.

In the chapters 4, 5 we have shown that for the generation of leptons the rotatory transformation in the plane is necessary. To this corresponds the group structure of the electro-weak interaction SU(2) x U(1).

Since SU(3) gauge invariance group describes the rotation in the three-dimensional space, we assume that the fields' rotation in the coordinate representation, according to the postulate of nonlinearity of NTEP, in this case must be achieved in the three-dimensional space

In the framework of the Standard Model theory the quark family is analogue to the lepton family and the Yang-Mils equation is some generalisation of the Dirac electron equation. In Quantum Chromodynamics we have quarks instead of electrons and gluons instead of photons, between which there are the strong interactions instead of electromagnetic interactions. Thus, formally, we can say that hadrons are described by two (meson) or three (barion) Dirac's lepton equations. Thus, we can name the Dirac's lepton equation conditionally as a "one quark" equation. Based on this analogy we suppose that:

1) the electromagnetic representation of the hadrons is similar to the electromagnetic representation of the leptons;

2) the hadron Lagrangian and equation are composed from two or three Lagrangian (or equations) of the lepton types, i.e. by two or three Dirac's equation Lagrangian (or Dirac's equation).

In other words, we suppose that the lepton Lagrangian or equation is conditionally the «one quark» Lagrangian or equation and the Yang-Mils equation "contains" three Dirac electron equation, as some their superposition (what means "it contains", we will refine more lately)

Therefore before passing to the derivation of the equation of hadrons, we will briefly recall the results of the theory of photons and leptons.

Our strategy is to proceed as far as possible in analogy with the case of electromagnetism.

3.0. The quantum and electromagnetic forms of the "one quark" equation

3.1. Derivation of electromagnetic form of one-quark equation

Within the framework of QED (Akhiezer and Berestetskii, 1969; Gottfried, and Weisskopf, 1984), the Maxwell equations are considered as field equations which describe the quantum mechanical state of photons or a photon system, taking into account the quantization rules for energy and wave vector $\omega = \varepsilon/\hbar$ and $k = p/\hbar$. The wave equations, in which wave functions $\vec{E}$ and $\vec{H}$ are vectors of the electromagnetic (EM) field, are the consequence of Maxwell equations:

$$\begin{aligned} \Delta\vec{E} - \frac{1}{c^2}\frac{\partial^2\vec{E}}{\partial t^2} = 0 \\ \Delta\vec{H} - \frac{1}{c^2}\frac{\partial^2\vec{H}}{\partial t^2} = 0 \end{aligned}, \qquad (11.3.1)$$

An plane electromagnetic wave, propagating in any direction (e.g., y-direction), can have two line polarizations $(\mathrm{E}_x, \mathrm{H}_z)$ and $(\mathrm{E}_z, \mathrm{H}_x)$ or one circular polarization $(\mathrm{E}_x, \mathrm{E}_z, \mathrm{H}_x, \mathrm{H}_z)$; thus it contains only four component of field vectors:

$$\vec{\Phi}(y) = \{\mathrm{E}_x, \mathrm{E}_z, \mathrm{H}_x, \mathrm{H}_z\}, \tag{11.3.2}$$

and $\mathrm{E}_y = \mathrm{H}_y = 0$ for all transformations. In this case the EM wave equations (11.3.1) can be rewrite as following:

$$\left(\frac{\partial^2}{\partial t^2} - c^2 \vec{\nabla}^2\right) \vec{\Phi}(y) = 0, \tag{11.3.3}$$

where $\vec{\Phi}(y)$ is any of the above electromagnetic wave field vectors (11.3.2). Taking into account that $\hat{\varepsilon} = i\hbar(\partial/\partial t), \hat{\vec{p}} = -i\hbar\vec{\nabla}$ are correspondingly the operators of energy and momentum, and

$$(\hat{\alpha}_o \hat{\varepsilon})^2 = \hat{\varepsilon}^2, \left(\hat{\vec{\alpha}}\hat{\vec{p}}\right)^2 = \hat{\vec{p}}^2, \tag{11.3.4}$$

where $\hat{\alpha}_0$; $\hat{\vec{\alpha}}$; $\hat{\beta} \equiv \hat{\alpha}_4$ are Dirac's matrices, the equation (11.3.3) can also be represented in a matrix form:

$$\left[(\hat{\alpha}_o \hat{\varepsilon})^2 - c^2 \left(\hat{\vec{\alpha}}\ \hat{\vec{p}}\right)^2\right] \Phi = 0, \tag{11.3.5}$$

Factoring (11.3.5) and multiplying it on the left by the Hermitian-conjugate function Φ^+, we get:

$$\Phi^+ \left(\hat{\alpha}_o \hat{\varepsilon} - c\hat{\vec{\alpha}}\ \hat{\vec{p}}\right) \left(\hat{\alpha}_o \hat{\varepsilon} + c\hat{\vec{\alpha}}\ \hat{\vec{p}}\right) \Phi = 0, \tag{11.3.6}$$

Equation (11.3.6) may be broken down into two Dirac-like equations without mass:

$$\begin{cases} \left(\hat{\alpha}_o \hat{\varepsilon} + c\hat{\vec{\alpha}}\hat{\vec{p}}\right)\Phi = 0 \\ \Phi^+ \left(\hat{\alpha}_o \hat{\varepsilon} - c\hat{\vec{\alpha}}\hat{\vec{p}}\right) = 0 \end{cases}, \tag{11.3.7}$$

Note that the system of equations (11.3.7) is identical to the equation (11.3.5) and can be represented (Akhiezer and Berestetskii, 1965; Levich, Myamlin and Vdovin, 1973) as a system of quantum equations for a photon in Hamilton's form. At the same time in the electromagnetic interpretation they are the equations of EM waves.

Actually, it is not difficult to show that only in the case when the $\Phi(y)$-matrix has the form:

$$\Phi(y) = \begin{pmatrix} \Phi_1 \\ \Phi_2 \\ \Phi_3 \\ \Phi_4 \end{pmatrix} = \begin{pmatrix} \mathrm{E}_x \\ \mathrm{E}_z \\ i\mathrm{H}_x \\ i\mathrm{H}_z \end{pmatrix}, \ \Phi^+(y) = \begin{pmatrix} \mathrm{E}_x & \mathrm{E}_z & -i\mathrm{H}_x & -i\mathrm{H}_z \end{pmatrix}, \tag{11.3.8}$$

the equations (11.3.7) are the right Maxwell-like equations of the retarded and advanced electromagnetic waves. Actually, substituting (11.3.8) into (11.3.7), we obtain:

$$\begin{cases} \frac{1}{c}\frac{\partial\, \mathrm{E}_x}{\partial\, t} - \frac{\partial\, \mathrm{H}_z}{\partial\, y} = 0 \\ \frac{1}{c}\frac{\partial\, \mathrm{H}_z}{\partial\, t} - \frac{\partial\, \mathrm{E}_x}{\partial\, y} = 0 \\ \frac{1}{c}\frac{\partial\, \mathrm{E}_z}{\partial\, t} + \frac{\partial\, \mathrm{H}_x}{\partial\, y} = 0 \\ \frac{1}{c}\frac{\partial\, \mathrm{H}_x}{\partial\, t} + \frac{\partial\, \mathrm{E}_z}{\partial\, y} = 0 \end{cases}, \qquad (11.3.9') \qquad \begin{cases} \frac{1}{c}\frac{\partial\, \mathrm{E}_x}{\partial\, t} + \frac{\partial\, \mathrm{H}_z}{\partial\, y} = 0 \\ \frac{1}{c}\frac{\partial\, \mathrm{H}_z}{\partial\, t} + \frac{\partial\, \mathrm{E}_x}{\partial\, y} = 0 \\ \frac{1}{c}\frac{\partial\, \mathrm{E}_z}{\partial\, t} - \frac{\partial\, \mathrm{H}_x}{\partial\, y} = 0 \\ \frac{1}{c}\frac{\partial\, \mathrm{H}_x}{\partial\, t} - \frac{\partial\, \mathrm{E}_z}{\partial\, y} = 0 \end{cases}, \qquad (11.3.9'')$$

For waves of any other direction the same results can be obtained by cyclic transposition of indices, or by a canonical transformation of matrices and wave functions. In the quantum form the wave function (11.3.8), regardless the direction of initial EM wave, does not have coordinate, but numerical indices, for the simple reason that the plane waves of any direction are equal. The same is correct for the equations of the massive particles, obtained further.

3.2. The intermediate photon and mass generation theory

In the NTEP, in contrast to SM, only a quantum of electromagnetic wave (photon) does not have mass. The postulate of generation of massive particles is: *the fields of an electromagnetic wave quantum must undergo a rotation transformation and breaking of the initial symmetry to generate the massive particle*.

The rotation transformation can be conditionally written in the following form:

$$\hat{R}\Phi \to \Phi', \qquad (11.3.10)$$

where $\hat{R}$ is the rotation operator for the transformation of a photon wave fields from linear state to curvilinear state, and Φ' is some final wave function:

$$\Phi' = \begin{pmatrix} \Phi'_1 \\ \Phi'_2 \\ \Phi'_3 \\ \Phi'_4 \end{pmatrix} = \begin{pmatrix} \mathrm{E}'_x \\ \mathrm{E}'_z \\ i\mathrm{H}'_x \\ i\mathrm{H}'_z \end{pmatrix}, \qquad (11.3.11)$$

which appears after the nonlinear transformation (11.3.1); 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'.

3.3. The description of rotation transformation in differential geometry

According to Maxwell (Jackson, 1999), the following term of equations (11.3.7) $\hat{\alpha}_0\hat{\varepsilon}\Phi = i\hbar\frac{\partial\Phi}{\partial t}$ contains the Maxwell's displacement current

$$j_{dis} = \frac{1}{4\pi}\frac{\partial\, \vec{\mathrm{E}}}{\partial\, t}, \qquad . \qquad (11.3.12)$$

The electrical field vector $\vec{\mathrm{E}}$, which moves along the curvilinear trajectory, can be written in the form:

$$\vec{\mathrm{E}} = -\mathrm{E}\cdot\vec{n}, \qquad (11.3.13)$$

where $\mathrm{E} = \left|\vec{\mathrm{E}}\right|$, and $\vec{n}$ is the normal unit-vector of the curve, directed, e.g., to the center of ring. Then:

$$\frac{\partial\,\vec{\mathrm{E}}}{\partial\,t} = -\frac{\partial\,\vec{\mathrm{E}}}{\partial\,t}\vec{n} - \mathrm{E}\frac{\partial\,\vec{n}}{\partial\,t}, \qquad (11.3.14)$$

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

$$\frac{\partial\,\vec{n}}{\partial\,t} = -\upsilon_p \mathrm{K}\vec{\tau}\,, \qquad (11.3.15)$$

where $\vec{\tau}$ is the tangential unit-vector, $\upsilon_p \equiv c$ is the electromagnetic wave velocity, $\mathrm{K} = 1/r_p$ 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:

$$\vec{j}_{dis} = -\frac{1}{4\pi}\frac{\partial\,\mathrm{E}}{\partial\,t}\vec{n} + \frac{1}{4\pi}\omega_p \mathrm{E}\cdot\vec{\tau}\,, \qquad (11.3.16)$$

where $\omega_p = \dfrac{m_p c^2}{\hbar} = \dfrac{\upsilon_p}{r_p} \equiv c\mathrm{K}$ is an angular velocity, $m_p c^2 = \varepsilon_p$ is photon energy, where m_p is some mass, corresponding to the energy ε_p. Obviously, the terms $\vec{j}_n = \dfrac{1}{4\pi}\dfrac{\partial\,\mathrm{E}}{\partial\,t}\vec{n}$ and $\vec{j}_\tau = \dfrac{\omega_p}{4\pi}\mathrm{E}\cdot\vec{\tau}$ are the normal and tangent components of the displacement current of the rotated electromagnetic wave accordingly.

3.4. A description of the rotation transformation in Rieman geometry

In order to generalize the Dirac equation in the form of Riemann geometry, we must 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:

$$D_\mu = \partial_\mu + \Gamma_\mu\,, \qquad (11.3.17)$$

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 the following term:

$$\hat{\alpha}_\mu \Gamma_\mu = \hat{\alpha}_0 \varepsilon_p + \hat{\vec{\alpha}}\ \vec{p}_p , \qquad (11.3.18)$$

where ε_p and p_p are the photon's energy and momentum respectively (not the operators). 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. If we represent the energy and momentum of the intrinsic field in equation (11.3.18), using the 4-potentials A_μ, which is the gauge field within the framework of SM, we obtain:

$$\hat{\alpha}_\mu \Gamma_\mu = \hat{\alpha}_0 \varepsilon_p + \hat{\vec{\alpha}}\ \vec{p}_p = e \alpha_\mu A^\mu \qquad (11.3.19)$$

According the analysis (Ryder, 1985), the gauge transformation is the rotation transformation of the field in the space of internal symmetry. In general case of a vector V^μ, its covariant derivative is

$$D_\nu V^\mu = \partial_\nu V^\mu + \Gamma^\mu_{\lambda\nu} V^\lambda , \qquad (11.3.20)$$

The quantities $\Gamma^\mu_{\lambda\nu}$, called the Christoffel's symbols or 'connection coefficients', clearly play a role of the vector potentials A^a_μ, which often are also called connection coefficients. In quantum field theory in case of a vector parallel transport (Kaempffer, 1965; Ryder, 1985) the equation

$$\frac{D\psi}{dx^\mu} = D_\mu \psi = \left(\partial_\mu - igM^a A^a_\mu \right)\psi , \qquad (11.3.21)$$

defines the covariant derivative of an arbitrary field ψ transforming under an arbitrary group, whose generators are represented by the matrices M^a appropriate to the representation of ψ.

3.5. An equation of the massive intermediate photon

As it follows from the previous sections, some additional terms $K = \hat{\beta}\ m_p c^2$, where m_p is mass of some intermediate photon and $m_p c^2 = \varepsilon_p$ is intermediate photon own energy, must appear in equation (2.2.6). Thus we have:

$$\left(\hat{\alpha}_o \hat{\varepsilon} - c\hat{\vec{\alpha}} \cdot \hat{\vec{p}} - K\right) \left(\hat{\alpha}_o \hat{\varepsilon} + c\hat{\vec{\alpha}} \cdot \hat{\vec{p}} + K\right)\Phi' = 0 , \qquad (11.3.22)$$

or

$$\left(\hat{\varepsilon}^2 - c^2 \hat{\vec{p}}^2 - m_p^2 c^4\right)\Phi' = 0, \qquad (11.3.23)$$

Equation (4.4.2) is similar to the Klein-Gordon equation, which describes the massive **scalar** field. It is not difficult to prove, using an electromagnetic form, that (4.4.2) is an equation of a massive **vector** particle.

3.6. The intermediate photon symmetry breaking

Factorizing (4.4.2) and multiplying it on the left side by Φ'^+, we obtain:

$$\Phi'^+ \left(\hat{\alpha}_o \hat{\varepsilon} - c\hat{\vec{\alpha}} \cdot \hat{\vec{p}} - \hat{\beta} m_p c^2\right)\left(\hat{\alpha}_o \hat{\varepsilon} + c\hat{\vec{\alpha}} \cdot \hat{\vec{p}} + \hat{\beta} m_p c^2\right)\Phi' = 0 , \qquad (11.3.24)$$

Now, we can separate the intermediate photon equation (11.3.1) into two massive waves, *advanced* and *retarded*, in order to obtain two new equations for the massive particles:

$$\left[\left(\hat{\alpha}_o \hat{\varepsilon} + c\hat{\vec{\alpha}}\ \hat{\vec{p}}\right) + \hat{\beta}\ m_p c^2\right]\psi = 0 , \qquad (11.3.25')$$

$$\psi^+\left[\left(\hat{\alpha}_o\hat{\varepsilon} - c\hat{\vec{\alpha}}\,\hat{\vec{p}}\right) - \hat{\beta}\,m_p c^2\right] = 0\,, \qquad (11.3.25'')$$

where

$$\psi = \begin{pmatrix}\psi_1\\ \psi_2\\ \psi_3\\ \psi_4\end{pmatrix} = \begin{pmatrix}E_x\\ E_z\\ iH_x\\ iH_z\end{pmatrix},\ \psi^+ = \begin{pmatrix}E_x & E_z & iH_x & iH_z\end{pmatrix}, \qquad (11.3.26)$$

is some new transformed EM wave function, which appears after the intermediate photon symmetry breaking. In the case of an electron-positron pair production, it must be $m_p = 2m_e$. So, we have from (11.3.25):

$$\left[\left(\hat{\alpha}_o\hat{\varepsilon} + c\hat{\vec{\alpha}}\,\hat{\vec{p}}\right) + 2\hat{\beta}\,m_e c^2\right]\psi = 0\,, \qquad (11.3.27')$$

$$\psi^+\left[\left(\hat{\alpha}_o\hat{\varepsilon} - c\hat{\vec{\alpha}}\,\hat{\vec{p}}\right) - 2\hat{\beta}\,m_e c^2\right] = 0\,, \qquad (11.3.27'')$$

Thus during the breaking of the intermediate photon, the non-charged massive particle is divided into two charged massive particle, which we conditionally can name as **semi-photons**. Obviously, the equations, which originate after the breaking-up of the intermediate photon, cannot be free positive and negative particle equations, but they have to be the particle equations with an external field.

Using a linear equation for the description of the law of energy conservation, we can write:

$$\pm\hat{\beta}\,m_e c^2 = -\varepsilon_{ex} - c\hat{\vec{\alpha}}\,\vec{p}_{ex} = -e\varphi_{ex} - e\hat{\vec{\alpha}}\,\vec{A}_{ex}\,, \qquad (11.3.28)$$

where "*ex*" is indices of "external" fields. Substituting (11.3.28) into (11.3.27), we obtain the Dirac equations with an external field, which appears in the theory automatically:

$$\left[\left(\hat{\alpha}_o\hat{\varepsilon} + c\hat{\vec{\alpha}}\ \hat{\vec{p}}\right) + \left(\hat{\alpha}_o\varepsilon_{ex} + c\hat{\vec{\alpha}}\ \vec{p}_{ex}\right) + \hat{\beta}\ mc^2\right]\psi = 0\,, \qquad (11.3.29')$$

$$\psi^+\left[\left(\hat{\alpha}_o\hat{\varepsilon} - c\hat{\vec{\alpha}}\ \hat{\vec{p}}\right) - \left(\hat{\alpha}_o\varepsilon_{ex} - c\hat{\vec{\alpha}}\ \vec{p}_{ex}\right) - \hat{\beta}\ mc^2\right] = 0\,, \qquad (11.3.29'')$$

Or in short

$$\left[\hat{\alpha}_0\left(\hat{\varepsilon} \mp \varepsilon_{ex}\right) + c\hat{\vec{\alpha}}\cdot\left(\hat{\vec{p}} \mp \vec{p}_{ex}\right) + \hat{\beta}\,m_e c^2\right]\psi = 0\,, \qquad (11.3.30)$$

On the other hand, the electron's own mass is formed due to the self-action of the fields of electron as an inherent characteristic of the electron:

$$\pm\hat{\beta}\,m_e c^2 = -\varepsilon_{in} - c\hat{\vec{\alpha}}\,\vec{p}_{in} = -e\varphi_{in} - e\hat{\vec{\alpha}}\,\vec{A}_{in}\,, \qquad (11.3.31)$$

so that any interaction energy we can be considered as additional mass.

3.7. Electromagnetic representation of one-quark and one-antiquark equations

In the case of the linear polarized waves we will obtain from (11.3.3) two pars of independent *spinor* equations for the electron and the positron, which contain only electric currents. This equations in the electromagnetic form are:

$$\begin{cases} \frac{1}{c}\frac{\partial E_x}{\partial t} - \frac{\partial H_z}{\partial y} = -i\frac{4\pi}{c} j_x^e \\ \frac{1}{c}\frac{\partial H_z}{\partial t} - \frac{\partial E_x}{\partial y} = 0 \end{cases}, (11.3.33') \quad \begin{cases} \frac{1}{c}\frac{\partial E_x}{\partial t} + \frac{\partial H_z}{\partial y} = -i\frac{4\pi}{c} j_x^e \\ \frac{1}{c}\frac{\partial H_z}{\partial t} + \frac{\partial E_x}{\partial y} = 0 \end{cases}, \quad (11.3.33'')$$

$$\begin{cases} \frac{1}{c}\frac{\partial E_z}{\partial t} + \frac{\partial H_x}{\partial y} = -i\frac{4\pi}{c} j_z^e \\ \frac{1}{c}\frac{\partial H_x}{\partial t} + \frac{\partial E_z}{\partial y} = 0 \end{cases}, (11.3.34') \quad \begin{cases} \frac{1}{c}\frac{\partial E_z}{\partial t} - \frac{\partial H_x}{\partial y} = -i\frac{4\pi}{c} j_z^e \\ \frac{1}{c}\frac{\partial H_x}{\partial t} - \frac{\partial E_z}{\partial y} = 0 \end{cases}, \quad (11.3.34'')$$

In the case of the circularly polarized wave we will obtain one bispinor equation for the neutrino and one for the antineutrino, which contain alternating electrical and magnetic currents. These equations in the electromagnetic form are:

$$\begin{cases} \frac{1}{c}\frac{\partial E_x}{\partial t} - \frac{\partial H_z}{\partial y} = -i\frac{4\pi}{c} j_x^e \\ \frac{1}{c}\frac{\partial H_z}{\partial t} - \frac{\partial E_x}{\partial y} = i\frac{4\pi}{c} j_z^m \\ \frac{1}{c}\frac{\partial E_z}{\partial t} + \frac{\partial H_x}{\partial y} = -i\frac{4\pi}{c} j_z^e \\ \frac{1}{c}\frac{\partial H_x}{\partial t} + \frac{\partial E_z}{\partial y} = i\frac{4\pi}{c} j_x^m \end{cases}, (11.3.35') \quad \begin{cases} \frac{1}{c}\frac{\partial E_x}{\partial t} + \frac{\partial H_z}{\partial y} = -i\frac{4\pi}{c} j_x^e \\ \frac{1}{c}\frac{\partial H_z}{\partial t} + \frac{\partial E_x}{\partial y} = i\frac{4\pi}{c} j_z^m \\ \frac{1}{c}\frac{\partial E_z}{\partial t} - \frac{\partial H_x}{\partial y} = -i\frac{4\pi}{c} j_z^e \\ \frac{1}{c}\frac{\partial H_x}{\partial t} - \frac{\partial E_z}{\partial y} = i\frac{4\pi}{c} j_x^m \end{cases}, \quad (11.3.35'')$$

3.8. The Dirac and the Yang-Mills equations

As it follows from the Standard Model theory (Pich, 2000; Peak and Varvell ; Okun, 1982), the quark family is analogue to a lepton family, and the Yang-Mils equation is the generalization of the Dirac's electron equation.

In short the Dirac lepton equation for an electron in the external field can be written in the form:

$$\hat{\alpha}_\mu \left(\hat{p}_\mu + p_\mu^e\right) \psi + \hat{\beta}\ m_e c^2 \psi = 0 \quad (11.1.36)$$

where $\mu = 0,1,2,3$, $\hat{p}_\mu = \{\hat{\varepsilon}, c\hat{\vec{p}}\}$ is operator of energy and momentum, $p_\mu^e = \{\varepsilon_{ex}^e, c\vec{p}_{ex}^{\,e}\}$ is energy and momentum in the external electromagnetic field, where $\varepsilon_{ex}^e = e\varphi$, $\vec{p}_{ex}^{\,e} = \frac{e}{c}\vec{A}$.

The Yang-Mills equation for one quark may by written similarly to (11.1.1) as follows (Pich, 2000; Peak and Varvell ; Okun, 1982):

$$\hat{\alpha}_\mu \left(\hat{p}_\mu + p_\mu^q\right) \psi_q + \hat{\beta}\ m_q c^2 \psi_q = 0\,, \quad (11.1.37)$$

where ψ_q are the quark wave function, $p_\mu^q \equiv icg\vec{A}_\mu$ with $\vec{A}_\mu = \frac{1}{2}\sum_{a=1}^{8} A_\mu^a \lambda_a$ is the potential of the gluon field, λ_a are Gell-Mann matrices, g is a strong charge, and m_q is a quark mass. Thus, we have quarks instead of lepton, gluons instead of photons, and strong interactions instead of electromagnetic interactions.

4.0. The derivation of Yang-Mills equation within the framework of NEPT

Let us assume that hadrons are some superposition of semi-photons and attempt to find the equations which describe this superposition of two or three semi-photons.

From above follows that the appearing of the lepton current, mass and interaction are the result of the same process – the rotation transformation and symmetry breaking of free EM wave quantum. According to postulates of NTEP the similar must occur in the case of hadrons.

But an essential difference there is here. The Dirac equation (11.1.36) is not a free lepton (e.g., electron) equation: the external field terms are used in Dirac's equation for the description of interaction between the electron and other particles. At the same time, the equation (11.1.37) is the equation of one "free" quark within the hadron and the interaction terms in the Yang-Mills equation must describe the internal field of a quark-quark interaction within the same hadron.

The fermions of the Standard Model are classified according to how they interact (or equivalently, by what charges they carry). There are six quarks (up, down, charm, strange, top, bottom), and six leptons (electron, electron neutrino, muon, muon neutrino, tau, tau neutrino). Pairs from each classification are grouped together to form a *generation*, with corresponding particles exhibiting similar physical behavior (see table).

	First generation		**Second generation**		**Third generation**	
Quarks	Up	u	Charm	c	Top	t
	Down	d	Strange	s	Bottom	b
Leptons	Electron	e−	Muon	μ−	Tau	τ−
	Electron neutrino	ν_e	Muon neutrino	ν_μ	Tau neutrino	ν_τ

On this base we can suppose that first generation hadrons, which consist of Up- and Down- quarks must be described by electron spinor and neutrino bispinor.

4.1. Quantum form of "three quark" equations without currents – masses – interactions

The system of the wave equations of first order (11.3.7)

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

is like the Dirac equations without mass:

We assume that the hadrons are the three-dimensional superposition of spinor particles (fermions) (in the general case it is possible to assume that in this superposition can participate simultaneously retarded and advanced waves). Thus, the equations, from which it is possible to compose the quark system, e.g., proton, must be of the following type:

$$\begin{cases}\left(\hat{\alpha}_o\hat{\varepsilon}+c\hat{\vec{\alpha}}\hat{\vec{p}}\right)\Phi_1=0\\ \left(\hat{\alpha}_o\hat{\varepsilon}+c\hat{\vec{\alpha}}\hat{\vec{p}}\right)\Phi_2=0\\ \left(\hat{\alpha}_o\hat{\varepsilon}+c\hat{\vec{\alpha}}\hat{\vec{p}}\right)\Phi_3=0\end{cases}, \qquad \begin{cases}\Phi_1^+\left(\hat{\alpha}_o\hat{\varepsilon}-c\hat{\vec{\alpha}}\hat{\vec{p}}\right)=0\\ \Phi_2^+\left(\hat{\alpha}_o\hat{\varepsilon}-c\hat{\vec{\alpha}}\hat{\vec{p}}\right)=0,\\ \Phi_3^+\left(\hat{\alpha}_o\hat{\varepsilon}-c\hat{\vec{\alpha}}\hat{\vec{p}}\right)=0\end{cases}$$

where $\Phi_1=\Phi_1(y)$, $\Phi_2=\Phi_2(x)$, $\Phi_3=\Phi_3(z)$.. After the rotation transformation these functions become the wave functions of the massive particles, which are designated below by italics. In this case according to (Kiryakos, 2010d) in the matrix form these wave functions are expressed as EM of field as follows:

$$\psi(x)=\begin{pmatrix}E_z\\E_y\\iH_z\\iH_y\end{pmatrix}, \qquad \psi(y)=\begin{pmatrix}E_x\\E_z\\iH_x\\iH_z\end{pmatrix}, \qquad \psi(z)=\begin{pmatrix}E_y\\E_x\\iH_y\\iH_x\end{pmatrix}, \qquad \psi^+(x)=\left(E_z\ \ E_y\ -iH_z\ -iH_y\right),$$

$$\psi^+(y)=\left(E_x\ \ E_z\ -iH_x\ -iH_z\right),\ \psi^+(z)=\left(E_y\ \ E_x\ -iH_y\ -iH_x\right).$$

The Pauli matrices are (Ryder, 1985) generators of a 2D rotation. So, for the "three quark" electromagnetic representation, we must use the generators of a 3D rotation, which are the known photon spin 3x3-matrices $\hat{\vec{S}}$ of O(3) group, which are identical with the part of Yang-Mills matrices:

$$\hat{S}_1=\begin{pmatrix}0&0&0\\0&0&-i\\0&i&0\end{pmatrix},\ \hat{S}_2=\begin{pmatrix}0&0&i\\0&0&0\\i&0&0\end{pmatrix},\ \hat{S}_3=\begin{pmatrix}0&-i&0\\i&0&0\\0&0&0\end{pmatrix}, \qquad (11.4.1)$$

We will use as "three quark" equation for the particle and antiparticle without currents – masses – interactions the following form:

$$\left({}^6\hat{\alpha}_o\hat{\varepsilon}-c\ {}^6\hat{\vec{\alpha}}\ \hat{\vec{p}}\right){}^6\Phi=0, \qquad (11.4.2')$$

$${}^6\Phi^+\left({}^6\hat{\alpha}_o\hat{\varepsilon}+c\ {}^6\hat{\vec{\alpha}}\ \hat{\vec{p}}\right)=0, \qquad (11.4.2'')$$

where the left upper index "6" means that these matrices are 6x6-matrices of the following type:

$${}^6\hat{\vec{\alpha}}=\begin{pmatrix}\hat{0}&\hat{\vec{S}}\\ \hat{\vec{S}}&\hat{0}\end{pmatrix},\ {}^6\hat{\alpha}_0=\begin{pmatrix}\hat{S}_0&\hat{0}\\ \hat{0}&\hat{S}_0\end{pmatrix},\ {}^6\hat{\alpha}_4\equiv{}^6\hat{\beta}=\begin{pmatrix}\hat{S}_0&\hat{0}\\ \hat{0}&-\hat{S}_0\end{pmatrix}, \qquad (11.4.3)$$

where $\hat{S}_0=\hat{1}$, and the wave function ${}^6\Phi=\begin{pmatrix}\vec{E}\\ i\vec{H}\end{pmatrix}$ is a 6x1 matrix.

It is not difficult to test that the above matrices give the right electromagnetic expressions of a bilinear form of the theory:

the energy density : ${}^6\Phi^+\ {}^6\hat{\alpha}_0\ {}^6\Phi=\vec{E}^2+\vec{H}^2=8\pi U$,

the Poynting vector (and momentum density also): $\vec{S}_P=\frac{1}{8\pi}{}^6\Phi^+\ {}^6\vec{\alpha}\ {}^6\Phi$,

and the 1st scalar of the electromagnetic field: ${}^6\Phi^+\ {}^6\hat{\alpha}_4\ {}^6\Phi=2\left(\vec{E}^2-\vec{H}^2\right)=4\pi F_{\mu\nu}F^{\mu\nu}$.

4.2. EM form of “three quark” equations without the currents-masses-interactions

It follows from the above that the proton and antiproton equations (without the currents-masses-interactions) can be represented by three “one quark” equations (without the currents-masses-interactions) of a type (11.4.2), i.e. by three electron equations, or three pairs, of scalar Maxwell equations (one pair per each co-ordinate). Obviously, there is a possibility of two directions of rotations of each quark (the left and the right quarks). Therefore, the 6+6 scalar equations for the proton description must exist, as well as the 6+6 equations for the antiproton description.

Let us find at first these equations without mass (i.e. without an inner interaction), assuming the mass-interaction terms equal to zero. Using (11.4.3), we obtain from the equations (11.4.2’) or (11.4.2’’) Maxwell-like equations without current:

$$\frac{1}{c}\frac{\partial}{\partial t}\begin{pmatrix} E_x \\ E_y \\ E_z \\ iH_x \\ iH_y \\ iH_z \end{pmatrix} + \left[\frac{\partial}{\partial x}\begin{pmatrix} 0 \\ H_z \\ -H_y \\ 0 \\ -iE_z \\ iE_y \end{pmatrix} + \frac{\partial}{\partial y}\begin{pmatrix} -H_z \\ 0 \\ H_x \\ iE_z \\ 0 \\ -iE_x \end{pmatrix} + \frac{\partial}{\partial z}\begin{pmatrix} H_y \\ -H_x \\ 0 \\ -iE_y \\ iE_x \\ 0 \end{pmatrix}\right] = 0, \qquad (11.4.4)$$

In the case of superposition of three photons, we obtain from (11.4.4):

$$\begin{cases} \frac{1}{c}\frac{\partial E_x}{\partial t} - \frac{\partial H_z}{\partial y} = 0, & a \\ \frac{1}{c}\frac{\partial H_z}{\partial t} - \frac{\partial E_x}{\partial y} = 0, & a' \\ \frac{1}{c}\frac{\partial E_y}{\partial t} - \frac{\partial H_x}{\partial z} = 0, & b \\ \frac{1}{c}\frac{\partial H_x}{\partial t} - \frac{\partial E_y}{\partial z} = 0, & b' \\ \frac{1}{c}\frac{\partial E_z}{\partial t} - \frac{\partial H_y}{\partial x} = 0, & c \\ \frac{1}{c}\frac{\partial H_y}{\partial t} - \frac{\partial E_z}{\partial x} = 0, & c' \end{cases} \qquad (11.4.5’) \qquad \begin{cases} \frac{1}{c}\frac{\partial E_z}{\partial t} + \frac{\partial H_x}{\partial y} = 0, & a \\ \frac{1}{c}\frac{\partial H_x}{\partial t} + \frac{\partial E_z}{\partial y} = 0, & a' \\ \frac{1}{c}\frac{\partial E_x}{\partial t} + \frac{\partial H_y}{\partial z} = 0, & b \\ \frac{1}{c}\frac{\partial H_y}{\partial t} + \frac{\partial E_x}{\partial z} = 0, & b' \\ \frac{1}{c}\frac{\partial E_y}{\partial t} + \frac{\partial H_z}{\partial x} = 0, & c \\ \frac{1}{c}\frac{\partial H_z}{\partial t} + \frac{\partial E_y}{\partial x} = 0, & c' \end{cases} \qquad (11.4.5’’)$$

As we can see, each pair of equations *a, b, c* describes a separate semi-photons. The fields vectors of equations (11.4.5’) rotate in the planes *XOZ*, *ZOY*, *YOX*; and similarly the fields’ vectors of equations (11.4.5’’) rotate in the planes *XOY*, *YOZ* , *ZOX*.

4.3. Description of appearance of currents-masses-interactions in the differential geometry

The spinor theory shows that the appearance of the internal interaction terms is bounded by three vectors $\vec{E}, \vec{H}, \vec{S}_P$, moving along the curvilinear trajectory. These vectors represent the moving trihedral of Frenet-Serret (Gray, 1997). In a general case, when the electromagnetic wave field vectors of e.g. three-quark particles move along the spatial curvilinear trajectories, not only the additional term defined by the curvature appears, but also the terms that are defined by the torsion of the trajectory.

Actually, in this case we have:

$$\frac{\partial \vec{E}}{\partial t} = -\frac{\partial E}{\partial t}\vec{n} - E\frac{\partial \vec{n}}{\partial t}, \quad \frac{\partial \vec{H}}{\partial t} = \frac{\partial \vec{H}}{\partial t}\vec{b} + H\frac{\partial \vec{b}}{\partial t} \tag{11.4.6}$$

where $\vec{b}$ is a binormal vector. According to Frenet-Serret formulas, we have:

$$\frac{\partial \vec{n}}{\partial t} = -\upsilon_p \mathrm{K}\vec{\tau} + \upsilon_p \mathrm{T}\vec{b}, \quad \frac{\partial \vec{b}}{\partial t} = -\upsilon_p \mathrm{T}\vec{n} \tag{11.4.7}$$

where $\mathrm{T} = \frac{1}{r_{\mathrm{T}}}$ is the torsion of the trajectory, and r_{T} is the torsion radius. Thus, the displacement currents can be written in the form:

$$\vec{j}_i^{\,e} = -\frac{1}{4\pi}\frac{\partial E_i}{\partial t}\vec{n} + {}^{\tau}j_i^e\vec{\tau} + {}^{b}j_i^e\vec{b}, \quad \vec{j}_k^{\,m} = \frac{1}{4\pi}\frac{\partial H_k}{\partial t}\vec{b} + {}^{n}j_k^m\vec{n} \tag{11.4.8'}$$

or

$$\vec{j}^{\,e} = -\frac{1}{4\pi}\frac{\partial E}{\partial t}\vec{n} + \frac{1}{4\pi}\omega_{\mathrm{K}}E\cdot\vec{\tau} - \frac{1}{4\pi}\omega_{\mathrm{T}}E\cdot\vec{b}, \quad \vec{j}^{\,m} = \frac{1}{4\pi}\frac{\partial H}{\partial t}\vec{b} - \frac{1}{4\pi}\omega_{\mathrm{T}}H\cdot\vec{n} \tag{11.4.8''}$$

where ${}^{\tau}j_i^e = \frac{1}{4\pi}\omega_{\mathrm{K}}E_i\cdot\vec{\tau}$ and ${}^{b}j_i^e = -\frac{1}{4\pi}\omega_{\mathrm{T}}E_i\cdot\vec{b}$ are electrical currents, ${}^{n}j_i^m = \frac{1}{4\pi}\omega_{\mathrm{T}}H_i\cdot\vec{n}$ are magnetic currents, $i,k = x,y,z$; $\omega_{\mathrm{T}} = \frac{\upsilon_p}{r_{\mathrm{T}}} \equiv c\mathrm{T}$ and $\omega_K = \frac{\upsilon_p}{r_K} \equiv c\mathrm{K}$ we name as the torsion and curvature angular velocities.

Thus, we can obtain the following electromagnetic representation of Yang-Mills equations with the mass terms:

$$\begin{cases} \frac{1}{c}\frac{\partial E_x}{\partial t} - \frac{\partial H_z}{\partial y} = {}^{\tau}j_x^e + {}^{b}j_x^e, a \\ \frac{1}{c}\frac{\partial H_z}{\partial t} - \frac{\partial E_x}{\partial y} = {}^{n}j_z^m, \quad a' \\ \frac{1}{c}\frac{\partial E_y}{\partial t} - \frac{\partial H_x}{\partial z} = {}^{\tau}j_y^e + {}^{b}j_y^e, b \\ \frac{1}{c}\frac{\partial H_x}{\partial t} - \frac{\partial E_y}{\partial z} = {}^{n}j_x^m, \quad b' \\ \frac{1}{c}\frac{\partial E_z}{\partial t} - \frac{\partial H_y}{\partial x} = {}^{\tau}j_z^e + {}^{b}j_z^e, c \\ \frac{1}{c}\frac{\partial H_y}{\partial t} - \frac{\partial E_z}{\partial x} = {}^{n}j_y^m, \quad c' \end{cases}, \quad (11.4.9')$$

$$\begin{cases} \frac{1}{c}\frac{\partial E_z}{\partial t} + \frac{\partial H_x}{\partial y} = {}^{\tau}j_z^e + {}^{b}j_z^e, a \\ \frac{1}{c}\frac{\partial H_x}{\partial t} + \frac{\partial E_z}{\partial y} = {}^{n}j_x^m, \quad a' \\ \frac{1}{c}\frac{\partial E_x}{\partial t} + \frac{\partial H_y}{\partial z} = {}^{\tau}j_x^e + {}^{b}j_x^e, b \\ \frac{1}{c}\frac{\partial H_y}{\partial t} + \frac{\partial E_x}{\partial z} = {}^{n}j_y^m, \quad b' \\ \frac{1}{c}\frac{\partial E_y}{\partial t} + \frac{\partial H_z}{\partial x} = {}^{\tau}j_y^e + {}^{b}j_y^e, c \\ \frac{1}{c}\frac{\partial H_z}{\partial t} + \frac{\partial E_y}{\partial x} = {}^{n}j_z^m, \quad c' \end{cases}, \quad (11.4.9'')$$

Thus, within the framework of electromagnetic representation, a proton is topologically the superposition of three rings. Therefore, we can suppose that it has a composition of a trefoil loop:

As we noted during the analysis of electromagnetic representation of electron equation, the charge, mass and interaction between the particles appear simultaneously during the rotation transformation and separation of a photon. In other words, the appearance of currents at rotation transformation of a "linear" photon simultaneously describes the generation of the charge, masses, and interactions of inner electron parts.

Since in this case we have, conditionally speaking, three electromagnetic equations of electron, one should conclude that the EM masses of quarks, their charges, and interactions between them are described by nine currents of equations (11.4.9).

It is possible to assume that three of them, which are tangential electric currents, determine the charges and masses of quarks.

However, at the same time, all currents together (three electrical tangential, three electrical binormal, and three magnetic normal) must determine the interaction between quarks. Moreover, since we have a closed system, it can be assumed that at least one of the currents can be expressed through others. In this case, there are only eight different terms of interaction.

Note also that in case of a 3D-space we cannot mathematically consistently write the Yang-Mills-equation in electromagnetic form using the usual complex form, since the latter includes only the plane geometry. In this case, the algebra of Hamilton's quaternions most likely must be used, which is the expansion of the theory of complex analysis into 3D-space.

4.4. The description of appearance of current-mass-interaction terms within the framework of Rieman's geometry

The appearance of an additional derivative term follows from the general theory of vector motion along curvilinear trajectory. This subject was studied in vector analysis, in the differential geometry, and in the hypercomplex number theory many years ago (Madelung, 1957; Korn and Korn, 1961). The results are well known. Below, we consider some conclusions of these theories.

Any vector $\vec{F}(\vec{r},t)$ can have the following forms:

$$\vec{F}(\vec{r},t) = \vec{F}(x^0, x^1, x^2, x^3) = F^0\vec{e}_0 + F^1\vec{e}_1 + F^2\vec{e}_2 + F^3\vec{e}_3 = \\ = F_0\vec{e}^{\,0} + F_1\vec{e}^{\,1} + F_2\vec{e}^{\,2} + F_3\vec{e}^{\,3}, \quad (11.4.10)$$

where $F^0, F^1, F^2, F^3, F_0, F_1, F_2, F_3$ are the invariant and co-variant vector modulus, and $\vec{e}^{\,i}$ and $\vec{e}_i$ are the basis unit vectors that in general case change from point to point. When the vector moves along the curvilinear trajectory, the partial derivatives take the form:

$$\frac{\partial \vec{F}}{\partial x^j} = \frac{\partial F^i}{\partial x^j}\vec{e}_i + F^i\frac{\partial \vec{e}_i}{\partial x^j} = \frac{\partial F_i}{\partial x^j}\vec{e}^{\,i} + F_i\frac{\partial \vec{e}^{\,i}}{\partial x^j}, \quad (11.4.11)$$

where the following notations are used:

$$\frac{\partial \vec{e}_i}{\partial x^j} = \Gamma_{ij}^k \vec{e}_k = -\Gamma_{kj}^i \vec{e}^{\,k}, \quad (11.4.12)$$

(here $i, j, k, = 0,1,2,3$)

The coefficients Γ_{ij}^k are named Christoffel symbols, or the bound coefficients. Thus, for the y-direction of an initial photon

$$\begin{cases} \vec{E} = E_3\vec{e}^{\,3} \\ \vec{H} = H_1\vec{e}^{\,1} \end{cases}, \quad (11.4.13)$$

we will obtain in the case of its curvilinear motion:

$$\begin{cases} \dfrac{1}{c}\dfrac{\partial \vec{E}}{\partial t} = \dfrac{\partial E_3}{\partial x^0}\vec{e}^{\,3} + E_3\Gamma_{k0}^3\vec{e}^{\,k}, \quad \dfrac{\partial \vec{E}}{\partial y} = \dfrac{\partial E_3}{\partial x^2}\vec{e}^{\,3} + E_3\Gamma_{k2}^3\vec{e}^{\,k} \\ \dfrac{1}{c}\dfrac{\partial \vec{H}}{\partial t} = \dfrac{\partial H_1}{\partial x^0}\vec{e}^{\,1} + H_1\Gamma_{k0}^1\vec{e}^{\,k}, \quad \dfrac{\partial \vec{H}}{\partial y} = \dfrac{\partial H_1}{\partial x^2}\vec{e}^{\,1} + H_1\Gamma_{k2}^1\vec{e}^{\,k} \end{cases}, \quad (11.4.14)$$

We can obtain the same for the waves of two other directions.

As we can see, the additional terms have appeared, which the initial linear equations did not have. Thus, in a general case, when electromagnetic field vectors of the three-knot particles move along curvilinear trajectories, additional terms of the same type that we obtained in the case of Yang-Mills equation appear.

Note: within the framework of NEPT the Christoffel or Ricci symbols are not the abstract mathematical values. On one hand, they are physical values; namely, they are the currents that appeared due to the rotation and torsion of electromagnetic vectors. On the other hand, they have a geometrical sense: they are proportional to trajectory's curvature K, and to the trajectory's torsion T.

4.5. The hadrons' equations with own currents-masses-interactions terms

Let us examine the formation of hadrons, e.g., protons, from the point of view of proton-antiproton pair production in two-photon collisions (The L3 Collaboration, 2003)

$$\gamma + \gamma \to p^+ + p^-, \quad (11.4.15)$$

We should conclude from (11.4.1) that quarks themselves are produced simultaneously by interaction between them. In other words, the total energy of a proton must be equally divided between the quarks and gluons. Recall that we had the same in case of photoproduction of an electron-positron pair with the only difference that in the last case the interaction was external.

As a consequence of this result, we obtained a doubled value of the mass terms. Consequently, instead of (11.4.2), we will have

$$\begin{aligned} &\left[\left({}^6\hat{\alpha}_o\hat{\varepsilon} - c\,{}^6\hat{\vec{\alpha}}\ \hat{\vec{p}}\right) - \left({}^6\hat{\alpha}_o\varepsilon_l - c\,{}^6\hat{\vec{\alpha}}\ \vec{p}_l\right) - {}^6\hat{\beta}\ m_l c^2\right] \cdot {}^6\psi = 0 \\ &{}^6\psi^+\left[\left({}^6\hat{\alpha}_o\hat{\varepsilon} + c\,{}^6\hat{\vec{\alpha}}\ \hat{\vec{p}}\right) + \left({}^6\hat{\alpha}_o\varepsilon_l + c\,{}^6\hat{\vec{\alpha}}\ \vec{p}_l\right) + {}^6\hat{\beta}\ m_l c^2\right] = 0 \end{aligned}, \qquad (11.4.16)$$

where $l = 1,2,...,9$, enumerate the appropriate quark mass (currents) and gluon energy-momentums. According to (11.4.9) and (11.4.16), we have nine quark currents and nine gluon currents, so that the total energies of quarks and currents must be the same.

As in the case of leptons, the appearance of currents simultaneously describes the appearance of a charge, mass and interaction of hadrons.

5.0. Heuristic hadron models

We assume that the hadrons, as superposition of two or three lepton-like particles, are the superposition of two or three loops (rings) of EM waves. For example, the baryon model can have a form of the trefoil knot (Fig. 11.1):

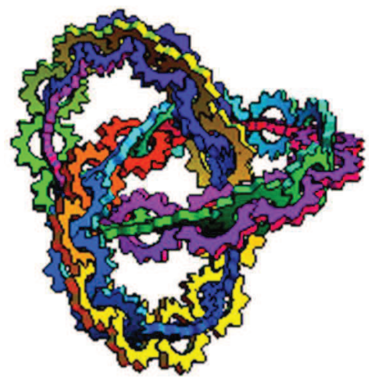

Fig. 11.1.

(This figure is from website MathWorld named 'Trefoil knot' http://mathworld.wolfram.com/TrefoilKnot.html , where the animation shows a series of gears motion along the Möbius strip's trefoil knot as the electric and magnetic field vectors motion).

A knot is defined as a closed, non-self-intersecting curve embedded into a 3D-space. Knot theory was given its first impetus when Lord Kelvin proposed a theory that atoms of Democritus are vortex loops (Kelvin,1867).

It is interesting that the trefoil and its mirror image are not equivalent. In other words, *the trefoil knot is a chiral object*. However, it is invertible.

The equation of one loop (ring) is the Dirac's equation that has a harmonic solution. Therefore, it can be supposed that EM hadrons represent a 3D superposition of two or three harmonic oscillations. In other words, EM hadrons are similar to space wave packets. According to Schrödinger (Schrödinger, 1926), the wave packets built from the harmonic waves (oscillations) do not have dispersion, i.e. they are stabile. Thus, as the first approximation, we can build the hadrons model as a space packet of a 3D superposition of two or three harmonics oscillations, i.e. as the Lissajoues figures.

Here, there are two difficulties: 1) the superpositions of harmonic oscillations are not topological figures as knots, because they are self-intersecting curves (maybe in this case the loops will not intersect because of the repulsion of currents, but this requires proof); 2) hadrons are not the superposition of complete harmonic waves, but half-periods of such waves. The description of the superposition of half-periods waves is absent in the literature. Therefore, we use the usual harmonic waves.

5.1. "Three quarks" (baryon) model

The models were constructed using MathCAD-program. We assume that the three-knot (baryon) model is built from three harmonics oscillation.

The harmonic oscillations are described by functions (for each co-ordinate axis):

$$X_{k,j} := r_1 \cdot \cos(\omega_1 \cdot t_j + \phi_1)$$
$$Y_{k,j} := r_2 \cdot \sin(-\omega_2 \cdot t_j + \phi_2)$$
$$Z_{k,j} := r_3 \cdot \sin(\omega_3 \cdot t_j + \phi_3)$$

If we choose the following oscillation parameters:

$$\omega_1 = 3, \quad \omega_2 = 2, \quad \omega_3 = 3,$$
$$\phi_1 = \phi_2 = \phi_3 = 0,$$
$$r_1 = r_2 = r_3 = 2 \ .$$

with $t_j := j \cdot 2 \cdot \frac{\pi}{N}$, where $N := 200$, $j := 0..N$, $k := 0..N$, then we obtain the following three-loops figure as a superposition of the above harmonic oscillations (Fig. 11.2):

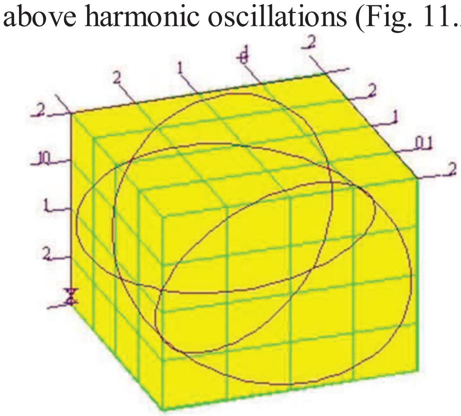

Fig. 11.2.

In order to show the rotation and twisting of a field vector, we change the parameter t_j to $t_j := \frac{j}{2.2}$. Then, we have (Fig. 11.3):

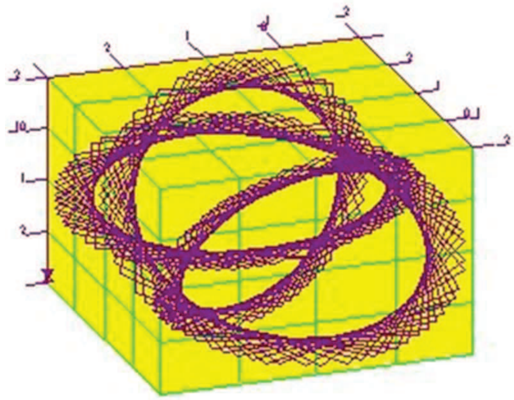

Fig. 11.3.

5.2. "Two quarks" model

In order to build the two-loops (meson) model, we choose in the above proton model the following equations $\omega_1 = 1$, $\omega_2 = 2$, $\phi_1 = \phi_2 = \phi_3 = 0$, $r_1 = r_2 = r_3 = 2$ and

$$X_{k,j} := r_1 \cdot \cos(\omega_1 \cdot t_j + \phi_1)$$
$$Y_{k,j} := r_2 \cdot \sin(-\omega_2 \cdot t_j + \phi_2)$$
$$Z_{k,j} := 0$$

Then, we obtain the Fig. 11.4:

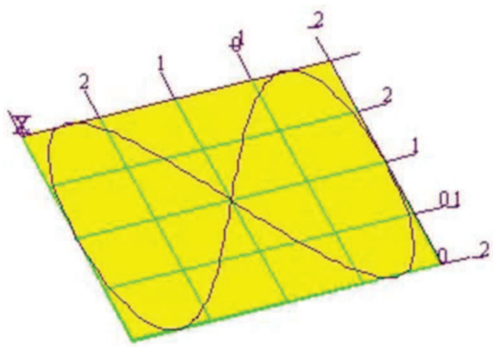

Fig. 11.4.

It is necessary to note that depending on the polarization of the curvilinear photon (plane, circular, elliptic), the meson models can have numerous different features.

We hope that further research will allow us to build more realistic models, which will give us an opportunity to calculate the properties of NEPT particle.

Thus, the models presented above differ a lot from the real NEPT hadrons and cannot be used for a calculation of particle's properties. However, they give several interesting consequences, which don't contradict the QCD results. These models give us an opportunity to compare some characteristics of EM hadrons with the real hadrons. We will discuss below the results of the above theory and models for the purpose of explaining the difficulties of the modern theory of hadrons.

6.0. Discussion of results

1. ***The fractional charge of quarks***: according to the above results an electric field trajectory of the EM quark wave has not only a curvature, but also a torsion. Hence, the tangential current generated by the transport of the electrical field vector alternates along the space trajectory.

Consequently, the electric charge of one knot, as an integral with respect to this current, will be less than the electron charge. However, the total charge from all knots can be equal to electron's charge.

Furthermore, one of the frequencies has a negative sign. This result can be compared to the fact that, in the baryon, two quarks have charges, which have opposite signs relative to the charge of the third quark.

2. ***Quarks confinement***: if quarks are two or three connected knots, then they cannot exist in a free state.

3. The mass of hadron will be determined by the sum of the masses of quarks themselves and the mass of energy of EM interaction fields in the box, which in this case is the hadron. (see as example the results of (Xiangdong and Wei, 1998; Xiangdong, 1994; Xiangdong, 2006))

4. Spin will be determined by the rotary motion of all these masses.

5. ***Correlation of masses of quarks***: in the NEPT model, masses are defined by the rotation frequencies of each knot. As we have seen, three-knot (see Fig. 9.1-3) is self-consistent only at a certain ratio of circular frequencies $\omega_1 : \omega_3 : \omega_2 = 3 : 3 : 2$. So, for the baryon model, two quark masses must be equal to each other, and not equal to the mass of the third quark. Similar, the two-knot (see Fig. 9.4) have frequencies ratio 2 to 3 and, therefore, the meson model must have two different quarks.

6. ***Nonlinearity of the Yang-Mills equation***: obviously, the Yang-Mills equation as the superposition of nonlinear electromagnetic waves is a nonlinear equation.

7. ***The confinement of gluons.*** According to the NEPT, gluons are virtual photons by which the knots interact between themselves. Then, the radius of an action of these particles is limited by the space of a hadron.

8. ***The colours of quarks*:** it can be assumed that the colours of quarks can be identified with the quark currents since each of the model's knots has three different currents.

9. ***The colours of gluons*:** it can be assumed that colours of gluons can be identified with the currents of each of two half-periods of virtual photons; with this respect, these photons are bent in the inner space of the hadrons, and have currents of a different type.

10. ***The strong interactions***: It is believed that colour, like an electric charge, gives rise to a quantized field, massless, and with a spin of one, like a photon, that ensures the strong interaction. The proton-neutron force must be in reality a complicated force, a sort of "residual" force between the quarks.

According to Denis Wilkinson (Wilkinson, 1981), the strong interaction can appear analogically to Van der Waals forces between atoms, which are caused by electric charges inside the atoms. Their short range interaction is a special feature of these forces. At a great distance, these forces are considerably weaker than the Coulomb force, but they are considerably stronger than the Coulomb force at short distances. According to D. Willkinson, the strong interaction between protons appears as a "residue" from the strong interaction between the quarks inside of protons. Thus, the electromagnetic forces, which according to NEPT act between the quarks inside the proton, can explain very large forces of interaction between protons.

As we have seen, the NEPT has the possibilities to explain many features of QCD. Of course, further analysis is needed to confirm or reject some of the above assertions.