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Research Article

THE SUBSTANTIAL MODEL OF THE PHOTON

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ABSTRACT

It is shown that the angular frequency of the photon is nothing else than the averaged angular frequency of revolution of the electron cloud's center during emission and quantum transition between two energy levels in an atom. On assumption that the photon consists of charged particles of the vacuum field (of praons), the substantial model of a photon is constructed. Praons move inside the photon in the same way as they must move in the electromagnetic field of the emitting electron, while internal periodic wave structure is formed inside the photon. The properties of praons, including their mass, charge and speed, are derived in the framework of the theory of infinite nesting of matter. At the same time, praons are part of nucleons and leptons just as nucleons are the basis of neutron stars and the matter of ordinary stars and planets. With the help of the Lorentz transformations, which correlate the laboratory reference frame and the reference frame, co-moving with the praons inside the photon, transformation of the electromagnetic field components is performed. This allows us to calculate the longitudinal magnetic field and magnetic dipole moment of the photon, and to understand the relation between the transverse components of the electric and magnetic fields, connected by a coefficient in the form of the speed of light. The total rest mass of the particles making up the photon is found, it turns out to be inversely proportional to the nuclear charge number of the hydrogen-like atom, which emits the photon.

Keywords: matter waves; quantum gravity; electromagnetic interaction; magnetic moments; properties of photon.

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1. INTRODUCTION

As is known, the more elementary the particle is, the less we know about it. The photon, the concept of which appeared more than a hundred years ago in the writings of Albert Einstein, is not an exception. What seems surprising about this particle is the absence of the rest mass, but at the same time the presence of wave and corpuscle properties, high stability and the ability to travel over cosmic distances with low energy losses, the indissoluble connection between photons and charged particles in the processes of absorption and emission.

One of the modern methods of studying the photon structure is experiments on colliding photons with each other, with protons and electrons. These experiments show that at small distances a photon can be modelled in the form of fluxes of quarks and gluons [1]. These fluxes should participate in interactions as is prescribed in quantum electrodynamics.

In the oscillating model [2] a photon is regarded as an object periodically changing its volume, the speed of which is less than the speed of light. In this model, it is assumed that the rest mass of the photon with the greatest wavelength can be related to the initial conditions of the early Universe. Based on this assumption the estimate of the mass of the photon's inner part is made: $m_0 = 1.6 \cdot 10^{-67}$ kg. In contrast, in [3] it is considered that a photon has no proper mass, however under the influence of the vacuum field the effective mass appears.

In [4] the photon diameter is deemed equal to the wavelength ª on the ground that this dimension is the limit for the wave diffraction. The soliton model of the photon is constructed in [5], where the equation for the vector potential is used, which is similar to the generalized Schrödinger equation. In [6] it is indicated that the drawback of the soliton model is the difficulty to explain the origin of the soliton, which usually requires a nonlinear medium. The photon diameter according to [7] is equal to ª /® , and outside of the photon its field strength must decrease in inverse proportion to the distance to the photon's axis. This allows the photon to undergo interference in the Young's interference experiment. Description of a photon as a rotating particle in the framework of quantum electrodynamics is presented in [8].

Due to the lack of key information about the internal parameters of electromagnetic quanta, the existing models still require further development and specification, because they do not allow us to define concretely the actual structure of a photon, to relate it to the source of emission at the atomic level and to the experimental data. The purpose of this article is to fill this gap and to provide a more detailed and well-grounded substantial model of the photon. We will do it based on the theory of infinite nesting of matter and the substantial model of the electron [9].

We will start with considering the basic conditions of emission from a hydrogen-like atom and estimating the duration of emission, which is necessary to determine the photon's length in space and then to calculate its energy density. In Section 3, we will present the main components of the electric and magnetic fields that are created by the charge rotating around the nucleus in the near and wave zones. The energy flux of these fields leads to a standard formula for the charge emission. Our goal is to use certain electromagnetic field components of the rotating charge to find the equations of motion for the smallest charged particles of the vacuum field in Section 4. We consider these particles, called praons, as construction material not only for photons but also for any other elementary particles, including nucleons and leptons. Praons have mass and we use the Lorentz factor to describe their motion at relativistic velocities. This allows us to turn with the help of Lorentz transformations to the reference frame, co-moving with praons, and to understand their motion from the standpoint of a fixed photon.

In Section 5, based on the motion of praons in the electromagnetic field of the emitting electron, periodically changing in space and time, we construct the substantial model of the photon. Section 6 concerns the structure of the electromagnetic field and the strong gravitational field inside the photon and their interaction with praons, which ensures the photon's stability. In Sections 7, 8, 9 we derive the Lorentz factor for praons and the energy fluxes within the photon, the magnetic dipole moment, and the rest mass of the particles that make up the photon, respectively.

2. EMISSION OF A PHOTON FROM A HYDROGEN-LIKE ATOM

According to the Bohr relation, the energy of a photon as an electromagnetic quantum, emitted during the electron's transition from some energy level i to a lower level j, equals the difference between the total energies of the electron at these levels:

$$W = \hbar \mu_{ij} = \left| E_i - E_j \right|, \tag{1}$$

here $\hbar$ is the Dirac constant,

μ_{ij} is the angular frequency of the photon.

But how could we describe more clearly what is happening in the atom during emission of the quantum? For simplicity, let us assume that one electron is located in the central-type field of the hydrogen-like atom. If the electron matter rotates totally symmetrically relative to the nucleus, then the electron would not emit. This is due to the fact that for each charge element of the electron matter in an axisymmetric configuration there is a similar charge element on the opposite side of the axis, which is moving in the opposite direction. At large distances, the contribution of the nucleus and of these charge elements into the total electric field strength E and the magnetic induction B will be compensated, and the resulting energy flux will be close to zero.

Therefore, in order to produce emission the electron must move so that its center of inertia is sufficiently removed from the nucleus. Let us assume that the center of the electron cloud rotates at a distance r from the nucleus and is held in relative equilibrium by a force directed towards the nucleus. If the velocity of the cloud's center is equal to u, then for the equality of the central and centripetal forces we can write:

$$F_c = -\frac{Ze^2}{4®£_0 r^2}, \qquad \frac{Ze^2}{4®£_0 r^2} \approx \frac{m_e u^2}{r}, \tag{2}$$

where Z is the number of protons in the nucleus, e is the elementary charge, $£_0$ is the vacuum permittivity, m_e is the electron mass, so that F_c is the electric force between the positively charged nucleus with the charge Ze and the negatively charged electron.

In (2) we used the approximately equal symbol, since in case of emission the distance r will slowly decrease and the velocity will increase. Besides, we do not take into account the change in the intrinsic electromagnetic energy of the cloud due to the change in the radius and volume of the cloud as it approaches the nucleus. Then we use the standard formula for the power of the total electromagnetic emission from the elementary charge, rotating around a certain center [10]. If we consider the emitted energy per time dt up to the sign equal to the change in the total energy dE_e of the electron cloud, then we can write:

$$\frac{dE_e}{dt} = -\frac{¢\, e^2 µ^4 r^2}{6®£_0 c^3}\,, \tag{3}$$

here c is the speed of light, and a small coefficient $¢$ reflects the fact that the emission from the electron cloud as a dimensional figure should differ from the emission from of the rotating electron as a point.

Assuming that $u = µ r$, where $µ$ is the angular velocity of rotation of the electron cloud's center around the nucleus, from the ratio for the power $\frac{dE_e}{dt} = -F_e u$ and (3) we will find the magnitude of the force, decelerating the cloud's rotation:

$$F_e = \frac{¢\, e^2 u^3}{6®£_0 c^3 r^2}\,. \tag{4}$$

For the angular momentum of the cloud's center of mass and its rate of change under the influence of the force moment $F_e r$ we can write:

$$L \approx m_e u r\,, \qquad \frac{dL}{dt} \approx -F_e r\,. \tag{5}$$

In addition, we obtain the following:

$$\frac{dE_e}{dt} = -F_e u = -F_e \text{µ} r = \text{µ} \frac{dL}{dt}, \qquad \text{µ} = \frac{dE_e}{dL}, \tag{6}$$

i.e. the change in the electron cloud's energy with the change in the angular momentum of the cloud's center is proportional to the angular frequency of rotation.

Expressing from (2) the rotation speed in the form $u \approx \sqrt{\frac{Ze^2}{4\text{®£}_0 m_e r}}$ and substituting in (5), in view of (4) we arrive at the differential equation for the dependence of the distance r on the time:

$$\frac{d}{dt}\sqrt{\frac{Ze^2 m_e r}{4\text{®£}_0}} \approx \frac{\text{¢}\, Z^{3/2} e^5}{48\text{®}^{5/2}\text{£}_0^{5/2} c^3 m_e^{3/2} r^{5/2}}, \qquad r = \left(r_0^3 - \frac{\text{¢}\, Z e^4 t}{4\text{®}^2\text{£}_0^2 c^3 m_e^2} \right)^{1/3},$$

$$2 = \frac{4\text{®}^2\text{£}_0^2 c^3 m_e^2}{\text{¢}\, Z e^4}\left(r_i^3 - r_j^3\right) = \frac{256\text{®}^5\text{£}_0^5 \hbar^6 c^3}{\text{¢}\, Z^4 e^{10} m_e}\left(i^6 - j^6\right). \tag{7}$$

here r_0 is the distance to the cloud's center at the initial time.

Expression (7) approximately describes the small changes in the distance r over time for the rotational motion of the electron cloud. Besides the following condition must hold: $r \geq 0$, $t \leq t_0 = \frac{4\text{®}^2\text{£}_0^2 c^3 m_e^2 r_0^3}{\text{¢}\, Z e^4}$, where t_0 is the time of the cloud's center of mass falling onto the attracting center.

For example, if we assume that the distance changes from $r_0 = r_i = 4a_B$ to $r = r_j = a_B$, where a_B denotes the Bohr radius, then for the time of transition from the level $i = 2$ to the level

$j = 1$ at $¢ \approx 1$ and $Z = 1$ from (7) we obtain the value of the order of $² = 9.8 \cdot 10^{-10}$ s, that is the typical time of the electromagnetic quantum emission by the electron in atomic transitions. If we substitute the distance (7) in (3), taking into account $u = \mu r \approx \sqrt{\frac{Ze^2}{4®£_0 m_e r}}$, and integrate it over the time, we will find the total energy of the electron cloud:

$$E_e = const - \frac{Ze^2}{8®£_0 r}. \tag{8}$$

From (8) we see that if the electron moves from the energy level i at the energy level j, then the energy of the emitted electromagnetic quantum will amount to the value equal to the difference between the electron's energy levels in the atom: $E_i - E_j = -\frac{Ze^2}{8®£_0 r_i} + \frac{Ze^2}{8®£_0 r_j}$. This relation fully coincides with the Bohr condition for energies. This should have been expected, because from (2) it follows that the electrostatic energy of the electron at the level i is equal to the value $W_i = -\frac{Ze^2}{4®£_0 r_i}$, and the kinetic energy of the electron is $K_i = \frac{m_e u_i^2}{2} = \frac{Ze^2}{8®£_0 r_i}$. The total energy at the level i is supposed to be equal to the sum of these energies: $E_i = W_i + K_i = -\frac{Ze^2}{8®£_0 r_i}$.

From the condition $u = \mu r \approx \sqrt{\frac{Ze^2}{4®£_0 m_e r}}$ and (3) it follows that the power of the energy emission is strongly dependent on the current distance r:

$$\frac{dE_e}{dt} = -\frac{¢ Z^2 e^6}{96®^3 £_0^3 c^3 m_e^2 r^4}. \tag{9}$$

According to (9) we can assume that the basic energy of the electromagnetic quantum during the transition from the energy level i to the energy level j is emitted by the electron cloud near the level j, where the radius of rotation r of the electron cloud's center is less. In this case, we find explanation for the fact that the frequency of electromagnetic quanta μ_{ij} in (1) is close, but always less than the frequency of the electron cloud's rotation near the energy level j. If we consider at some time point the emitted electromagnetic quantum along its length in space, then its oscillation frequency should increase when moving from the front part of the quantum to its rear part, and the quantum energy density must reach the maximum closer to the rear part of the quantum.

The constant $h = 2\text{®}\hbar$ was introduced by Planck in 1900 while establishing the law of energy distribution in the blackbody spectrum. This constant turned out to be a universal quantity at the level of elementary particles and atoms, with the dimensionality of a quantum of action. Its role in determining the electromagnetic energy of quanta, despite the fact that the wave oscillation frequency inside these quanta in our opinion cannot be strictly constant, is quite similar to that of the Boltzmann constant in determining the average thermal energy of a set of particles through the temperature, with the energy spread of individual particles, which is always present.

We will show that the angular frequency μ_{ij} of the quantum is the averaged angular frequency $\bar{\mu}$ of rotation of the electron cloud's center at transition between the energy levels i and j. For $\bar{\mu}$ in view of (6) we have:

$$\bar{\mu} = \frac{1}{L_j - L_i} \int_{L_i}^{L_j} \mu \, dL = \frac{1}{L_j - L_i} \int_{L_i}^{L_j} dE_e = \frac{E_j - E_i}{L_j - L_i} = \frac{\Delta E_e}{\Delta L}.$$

At $\Delta L = \hbar$ the energy electromagnetic quantum is:

$$W = \left| \Delta E_e \right| = \hbar \bar{\mu} . \tag{10}$$

From comparison of (10) and (1) we see that $\mu_{ij} = \bar{\mu}$. However, if for some reason $\Delta L \neq \hbar$, the equality $\mu_{ij} = \bar{\mu}$ would not exist.

Since during the emission of quanta the electron's angular momentum changes, the change in the angular momentum should be carried away by the electromagnetic quantum. Photons or electromagnetic quanta, are attributed the angular momentum, equal to $\hbar$. Therefore, during emission the electron loses the angular momentum of the order of $\hbar$ and the same angular momentum is acquired by the photon; the electron loses the energy of the order of $h\neg$, where $\neg$ is the average rotation frequency of the electron's center of mass near the nucleus for the period of emission, and the photon acquires this energy. The electron acts in this case as a carrier particle that transfers its kinetic energy and angular momentum into the energy and angular momentum of the electromagnetic wave that are concentrated in the emitted photon.

3. THE EMISSION FROM THE ROTATING POINT CHARGE

Let us assume that a charged point particle with the charge q rotates by a circle of radius R_0 with the angular velocity μ and the orbital velocity $V_0 = \mu R_0$. We will place a spherical reference frame at the center of this circle and will seek for the components of the electromagnetic field strength from the rotating charge at some remote point with the radius-vector $\mathbf{R} = (x, y, z)$. The current position of the charge is given by the vector $\mathbf{R}_0 = (R_0 \cos \mu t, R_0 \sin \mu t, 0)$, so that the circle of rotation lies in the plane XOY.

In order to determine the electric field strength $\mathbf{E}$ and the magnetic field induction $\mathbf{B}$ in the first approximation we will use the formulas that take into account any motion of the charge in the special theory of relativity:

$$\mathbf{E} = \frac{q}{4 \circledR \pounds_0} \left[\frac{\mathbf{e}_{r'}}{r'^2} + \frac{r'}{c} \frac{d}{dt} \left(\frac{\mathbf{e}_{r'}}{r'^2} \right) + \frac{1}{c^2} \frac{d^2}{dt^2} \mathbf{e}_{r'} \right], \qquad \mathbf{B} = \frac{1}{c} \mathbf{e}_{r'} \times \mathbf{E}, \tag{11}$$

here $\mathbf{r}'=\mathbf{R}-\mathbf{R}_0(t')$ is the vector from the charge to the remote point at the early time point $t'=t-\frac{r'}{c}$,

$r'=\sqrt{(x-R_0\cos\mu t')^2+(y-R_0\sin\mu t')^2+z^2}$,

$\mathbf{e}_{r'}=\left(\frac{x-R_0\cos\mu t'}{r'},\frac{y-R_0\sin\mu t'}{r'},\frac{z}{r'}\right)$ is the unit vector, directed from the charge to the remote point, taken for the case of rotation of this charge by a circle at an early time point t'.

The formula (11) was first published by Oliver Heaviside in 1902. It was independently discovered by R. P. Feynman, in about 1950, and given in some lectures as a good way of thinking about synchrotron radiation [11].

From the definitions of t' and r' we see that they are mutually dependent. We will take for them the derivatives with respect to time:

$$\frac{dt'}{dt}=1-\frac{1}{c}\frac{dr'}{dt}, \qquad \frac{dr'}{dt}=\frac{\mu R_0}{r'}(x\sin\mu t'-y\cos\mu t')\frac{dt'}{dt},$$

and then we will express these derivatives independently from each other:

$$\frac{dt'}{dt}=\frac{1}{1+\frac{\mu R_0}{cr'}(x\sin\mu t'-y\cos\mu t')}, \qquad \frac{dr'}{dt}=\frac{\frac{\mu R_0}{r'}(x\sin\mu t'-y\cos\mu t')}{1+\frac{\mu R_0}{cr'}(x\sin\mu t'-y\cos\mu t')}.$$

If the orbital velocity $V_0=\mu R_0$ is significantly less than the speed of light c, as is the case for the electron in the atom, we see that:

$$\frac{dt'}{dt}\approx 1, \qquad \frac{dr'}{dt}\leq \mu R_0. \tag{12}$$

Taking the first time derivative of the unit vector of the original direction, we find:

$$\frac{de_{r'x}}{dt}=\frac{\mu R_0 \sin \mu t'}{r'}\frac{dt'}{dt}-\frac{x-R_0 \cos \mu t'}{r'^2}\frac{dr'}{dt}, \qquad \frac{de_{r'y}}{dt}=-\frac{\mu R_0 \cos \mu t'}{r'}\frac{dt'}{dt}-\frac{y-R_0 \sin \mu t'}{r'^2}\frac{dr'}{dt},$$

$$\frac{de_{r'z}}{dt}=-\frac{z}{r'^2}\frac{dr'}{dt}. \qquad (13)$$

Let us substitute in the right-hand side of (13) the time derivatives by their maximum values according to (12) and calculate the second time derivatives of the unit vector:

$$\frac{d^2 e_{r'x}}{dt^2}\approx \frac{\mu^2 R_0 \cos \mu t'}{r'}\frac{dt'}{dt}-\frac{\mu R_0 \sin \mu t'}{r'^2}\frac{dr'}{dt}-\frac{\mu^2 R_0^2 \sin \mu t'}{r'^2}\frac{dt'}{dt}+\frac{2\mu R_0 (x-R_0 \cos \mu t')}{r'^3}\frac{dr'}{dt}.$$

$$\frac{d^2 e_{r'y}}{dt^2}\approx \frac{\mu^2 R_0 \sin \mu t'}{r'}\frac{dt'}{dt}+\frac{\mu R_0 \cos \mu t'}{r'^2}\frac{dr'}{dt}+\frac{\mu^2 R_0^2 \cos \mu t'}{r'^2}\frac{dt'}{dt}+\frac{2\mu R_0 (y-R_0 \sin \mu t')}{r'^3}\frac{dr'}{dt}.$$

$$\frac{d^2 e_{r'z}}{dt^2}\approx \frac{2\mu R_0\, z}{r'^3}\frac{dr'}{dt}. \qquad (14)$$

For the components of the derivative $\frac{d}{dt}\left(\frac{\mathbf{e}_{r'}}{r'^2}\right)$ in (11), in view of (12) and (13), we obtain:

$$\frac{d}{dt}\left(\frac{e_{r'x}}{r'^2}\right)=\frac{1}{r'^2}\frac{de_{r'x}}{dt}-\frac{2e_{r'x}}{r'^3}\frac{dr'}{dt}\approx \frac{\mu R_0 \sin \mu t'}{r'^3}-\frac{2(x-R_0 \cos \mu t')}{r'^4}\frac{dr'}{dt}.$$

$$\frac{d}{dt}\left(\frac{e_{r'y}}{r'^2}\right)=\frac{1}{r'^2}\frac{de_{r'y}}{dt}-\frac{2e_{r'y}}{r'^3}\frac{dr'}{dt}\approx -\frac{\mu R_0 \cos \mu t'}{r'^3}-\frac{2(y-R_0 \sin \mu t')}{r'^4}\frac{dr'}{dt}.$$

$$\frac{d}{dt}\left(\frac{e_{r'z}}{r'^2}\right)=\frac{d}{dt}\left(\frac{z}{r'^3}\right)=-\frac{3z}{r'^4}\frac{dr'}{dt}. \qquad (15)$$

Substituting (14) and (15) in (11), we find the component of the electric field strength E_x:

$$E_x=\frac{q}{4\text{®}\pounds_0}\left[\begin{array}{l}\dfrac{x-R_0\cos\mu t'}{r'^3}+\dfrac{\mu R_0\sin\mu t'}{r'^2c}-\dfrac{2(x-R_0\cos\mu t')}{r'^3c}\dfrac{dr'}{dt}+\dfrac{\mu^2R_0\cos\mu t'}{r'c^2}-\\ -\dfrac{\mu R_0\sin\mu t'}{r'^2c^2}\dfrac{dr'}{dt}-\dfrac{\mu^2R_0^2\sin\mu t'}{r'^2c^2}\dfrac{dt'}{dt}+\dfrac{2\mu R_0(x-R_0\cos\mu t')}{r'^3c^2}\dfrac{dr'}{dt}\end{array}\right]. \qquad (16)$$

According to (12), $\frac{dr'}{dt}\le\mu R_0=V_0$, and then in (16) the third and seventh terms are less than the first term, since $V_0<<c$. Similarly, taking into account the relation $\frac{dt'}{dt}\approx 1$, the fifth and sixth terms in (16) are always less than the second term. As a result, leaving the greatest terms in (16) and (11), for the electromagnetic field components we have the following:

$$E_x=\frac{q}{4\text{®}\pounds_0}\left(\frac{x-R_0\cos\mu t'}{r'^3}+\frac{\mu R_0\sin\mu t'}{r'^2c}+\frac{\mu^2R_0\cos\mu t'}{r'c^2}\right).$$

$$E_y=\frac{q}{4\text{®}\pounds_0}\left(\frac{y-R_0\sin\mu t'}{r'^3}-\frac{\mu R_0\cos\mu t'}{r'^2c}+\frac{\mu^2R_0\sin\mu t'}{r'c^2}\right).$$

$$E_z=\frac{q}{4\text{®}\pounds_0}\left(\frac{z}{r'^3}-\frac{3z}{r'^3c}\frac{dr'}{dt}+\frac{2\mu R_0z}{r'^3c^2}\frac{dr'}{dt}\right)\approx\frac{qz}{4\text{®}\pounds_0r'^3}. \qquad (17)$$

$$B_x=\frac{q}{4\text{®}\pounds_0}\left(\frac{\mu R_0z\cos\mu t'}{r'^3c^2}-\frac{\mu^2R_0z\sin\mu t'}{r'^2c^3}\right),\qquad B_y=\frac{q}{4\text{®}\pounds_0}\left(\frac{\mu R_0z\sin\mu t'}{r'^3c^2}+\frac{\mu^2R_0z\cos\mu t'}{r'^2c^3}\right),$$

$$B_z = \frac{q}{4\pi\varepsilon_0}\left[\frac{\omega R_0}{r'^3 c^2}\left(R_0 - x\cos\omega t' - y\sin\omega t'\right) + \frac{\omega^2 R_0}{r'^2 c^3}\left(x\sin\omega t' - y\cos\omega t'\right)\right].$$

At large distances, when $\omega r' > c$, the last terms containing r' in the denominator start predominating in the electric field components (17), and the terms containing r'^2 in the denominator start predominating in the magnetic field components.

The Poynting vector or the electromagnetic energy flux equals:

$$\mathbf{S}_p = \varepsilon_0 c^2 [\mathbf{E}\times\mathbf{B}].$$

If in (17) we take into account only the last terms that remain at a great distance, then the Poynting vector components are as follows:

$$S_{px} = \frac{q^2\omega^2 R_0}{16\pi^2\varepsilon_0 r'^3 c}\left[\frac{\omega^2 R_0 \sin\omega t'(x\sin\omega t' - y\cos\omega t')}{c^2} - \frac{z^2\cos\omega t'}{r'^2}\right],$$

$$S_{py} = -\frac{q^2\omega^2 R_0}{16\pi^2\varepsilon_0 r'^3 c}\left[\frac{\omega^2 R_0 \cos\omega t'(x\sin\omega t' - y\cos\omega t')}{c^2} + \frac{z^2\sin\omega t'}{r'^2}\right], \qquad S_{pz} = \frac{q^2\omega^4 R_0^2 z}{16\pi^2\varepsilon_0 r'^3 c^3}.$$

We must first average the components S_{px} and S_{py} for one period of the charge's rotation, when the phase $\omega t'$ varies from 0 to 2π. Given that $\overline{S}_{pz} = S_{pz}$, we have:

$$\overline{S}_{px} = \frac{1}{2\pi}\int_0^{2\pi} S_{px}\, d\varphi = \frac{q^2\omega^4 R_0^2 x}{32\pi^2\varepsilon_0 r'^3 c^3}, \qquad \overline{S}_{py} = \frac{1}{2\pi}\int_0^{2\pi} S_{py}\, d\varphi = \frac{q^2\omega^4 R_0^2 y}{32\pi^2\varepsilon_0 r'^3 c^3}.$$

Now, integrating $\overline{\mathbf{S}}_p$ over the surface of the remote sphere we find the rate of the electromagnetic energy flux, averaged over the period:

$$\frac{dW_{em}}{dt} = \int \overline{\mathbf{S}}_p \cdot \mathbf{n}\, d\Sigma = \frac{q^2 \omega^4 R_0^2}{32\pi^2 \varepsilon_0 c^3} \int \frac{x^2 + y^2 + 2z^2}{R r'^3}\, d\Sigma = \frac{q^2 \omega^4 R_0^2}{6\pi \varepsilon_0 c^3}. \qquad (18)$$

here $\mathbf{n} = \left(\frac{x}{R}, \frac{y}{R}, \frac{z}{R} \right)$ is a unit vector perpendicular to the sphere surface, $d\Sigma = R^2 \sin\theta \, d\theta \, d\varphi$ is an area unit, for the spherical coordinates $x^2 + y^2 + z^2 = R^2$, $z = R\cos\theta$ and we assumed that $r' \approx R$.

The emission rate in (18) coincides with the result in (3), while for calculation instead of full expressions for the field we used only the field components from (17) that remain in the remote area.

4. PHOTON FORMATION

4.1. The near zone

We consider an electron in an atom as a flat disk, the center of which is shifted relative to the nucleus and is rotating around the nucleus during emission of a photon. After formation, a photon becomes an independent object and no longer depends on the fields generated by the emitting electron and the atomic nucleus. Now we need to build a model of a photon, to understand what it consists of, how it maintains the perpendicular structure of the electromagnetic field and why a photon is a stable object. For this purpose, we will turn to the results of [12,13], where the photon is regarded as an object consisting of tightly bound charged particles.

In [14] we assume the positively and negatively charged praons as the charged particles that permeate entire space in different directions and create the interaction forces between the electric charges. These particles are one of the components of the vacuum field, along with the graviton field, responsible for the occurrence of gravitational forces [15] in Le Sage's model. The mass to charge ratio found for praons turns out to be such as it follows from the coefficients of similarity between different levels of matter and from the theory of dimensions. According to the theory of infinite nesting of matter, praons make up the matter of nucleons just as nucleons make up the matter of neutron stars. Besides, the fluxes of charged praons are the cause of the Coulomb force, and inside of photons praons come into a state of steady and orderly rotation.

In the substantial model of electron [9], in a hydrogen atom in its ground state the average radius of the electron disk is assumed to be equal to the Bohr radius a_B, the minimum radius of the disk is $0.5 a_B$ and the maximum radius reaches $1.5 a_B$. These radii correlate with the electron density distribution according to the electron wave function and the solutions of Schrödinger equation. Close to the nucleus, at a radius less than $0.5 a_B$, the electron matter density decreases rapidly. We suppose that the fluxes of praons pass here along the axis OZ, perpendicular to the plane of the electron disk, without direct contact with the electron matter, interacting with the nucleus and electron only by means of the field. From the symmetry of fields of the nucleus and electron disk it follows that near the axis OZ the praon fluxes mostly move linearly, creating the basis of the emitted photon. Other praons that pass through the electron disk, after interaction with the charged matter of the disk, get into the photon shell with a cross-section of the order of the electron disk's size. The same pattern holds for the hydrogen-like atom.

For example, in [14] at a first approximation a photon is considered as a long, thin cylinder, rotating at the angular frequency $\mu = \frac{2® c}{a}$, where $ª$ is the wavelength of the photon. For a photon with the wavelength $ª = 1.21567 \cdot 10^{-7}$ m and the angular frequency $\mu = 1.54946 \cdot 10^{16}$ s^{-1}, which emerges in the hydrogen atom at the transition of the electron from the second to the first level in the Lyman series, we assume the average radius of the electron disk $4a_B$ as the photon radius. The total length of the photon is given by the expression $\ell = c²$, where ² is the duration of the photon emission by the atom, according to (7).

Let us analyze the electromagnetic field components at an arbitrary point in space $\mathbf{R} = (x, y, z)$, the coordinates x and y of which do not exceed much the orbit radius R_0 of the rotating emitting charge, and the coordinate z by its absolute value is much larger than the orbit radius: $|z| \gg R_0$. In this area, the condition $\mu r' < c$ holds, so that in (17) the first terms predominate. Turning to the hydrogen-like atom, in (17) we will also replace q with the negative charge of the electron $-e$, where e is the elementary charge, and will add to (17) the static electric field components from the charge $+Ze$ of the atomic nucleus, located in the center of the coordinate system. The result for the field components can be written as follows:

$$E_x = \frac{(Z-1)ex + eR_0 \cos \mu t'}{4 \circledR \pounds_0 r'^3}, \qquad E_y = \frac{(Z-1)ey + eR_0 \sin \mu t'}{4 \circledR \pounds_0 r'^3}, \qquad E_z = \frac{(Z-1)ez}{4 \circledR \pounds_0 r'^3}. \tag{19}$$

$$B_x = -\frac{e\mu R_0 \, z \cos \mu t'}{4 \circledR \pounds_0 r'^3 c^2}, \qquad B_y = -\frac{e\mu R_0 \, z \sin \mu t'}{4 \circledR \pounds_0 r'^3 c^2}, \qquad B_z = -\frac{e\mu R_0 \left(R_0 - x \cos \mu t' - y \sin \mu t' \right)}{4 \circledR \pounds_0 r'^3 c^2}.$$

The magnetic field component B_z in (19) oscillates in a complicated way. If we restrict ourselves to an area, where $|z| > R_0$, that is outside the atom, but with the near zone condition $\mu r' < c$, then we can assume $R \approx r'$ and $r' \approx |z|$. In this case, the component B_z can be neglected, since it would be $|z| / R_0$ times less than the components B_x and B_y.

The electric field components, depending on the multiplier $Z-1$, determine the constant field from the effective charge $(Z-1)e$ of the hydrogen-like atom, decreasing with the distance according to the Coulomb's law. This field should accelerate the charged praons, changing their energy. However, the emerging photon has the almost same number of positive and negative praons, which ensures the electroneutrality of the photon. These praons also interact strongly with each other and are in a bound state. Then the component E_z at sufficiently large distances r' will not influence the motion of particles in a neutral average photon.

As a result, the pattern of the moving field will be formed mainly by those components in E_x, E_y, B_x and B_y that are time-dependent. Introducing the transverse vectors $\mathbf{E}_\perp = (E_x, E_y, 0)$ and $\mathbf{B}_\perp = (B_x, B_y, 0)$, from (19) we find for those components the following:

$$\mathbf{E}_\perp = \frac{eR_0}{4\pi\varepsilon_0 r'^3}\hat{\mathbf{R}}_0(\omega t'), \qquad \mathbf{B}_\perp = -\frac{e\omega R_0 z}{4\pi\varepsilon_0 r'^3 c^2}\hat{\mathbf{R}}_0(\omega t'), \tag{20}$$

where the unit vector $\hat{\mathbf{R}}_0(\omega t') = (\cos\omega t', \sin\omega t', 0)$ determines the position of the rotating electron in the plane XOY at the early time point t'.

From (20) we see that the transverse components of the electric $\mathbf{E}_\perp$ and magnetic $\mathbf{B}_\perp$ fields rotate around the axis OZ at the angular frequency ω synchronously with the rotation of the vector $\hat{\mathbf{R}}_0(\omega t')$ and with the rotation of the electron in the atom. At the same time the component $\mathbf{E}_\perp$ is directed in space the same way as the radius vector of the electron at the early time, and the magnetic field $\mathbf{B}_\perp$ is directed oppositely.

We will write down the equation of motion of the negatively charged praons in the external electromagnetic field and will find the mode of their motion, using the general equations of motion in the same way as in [16,17]. The equation of motion with respect to the early time t' is determined by the Lorentz force:

$$m_{pre}\frac{d}{dt'}(\gamma\mathbf{V}) = -e_{pr}\mathbf{E} - e_{pr}\left[\mathbf{V}\times\mathbf{B}\right], \tag{21}$$

here m_{pre} is the invariant mass of a negatively charged praon,

$\gamma = \frac{1}{\sqrt{1-V^2/c^2}}$ is the Lorentz factor,

e_{pr} is the elementary charge for praon level of matter,

$\mathbf{V}$ is the particle velocity vector.

After substitution of the fields (20) into (21), we obtain for the motion of particles the following:

$$\frac{d}{dt'}(\gamma V_x) = -\frac{e e_{pr} R_0}{4\pi\varepsilon_0 m_{pre} r'^3}\cos(\omega t') - \frac{e e_{pr} \omega R_0 z V_z}{4\pi\varepsilon_0 m_{pre} r'^3 c^2}\sin(\omega t'),$$

$$\frac{d}{dt'}(\gamma V_y) = -\frac{e e_{pr} R_0}{4\pi\varepsilon_0 m_{pre} r'^3}\sin(\omega t') + \frac{e e_{pr} \omega R_0 z V_z}{4\pi\varepsilon_0 m_{pre} r'^3 c^2}\cos(\omega t'),$$

$$\frac{d}{dt'}(\gamma V_z) = \frac{e e_{pr} \omega R_0 z}{4\pi\varepsilon_0 m_{pre} r'^3 c^2}\left[V_x \sin(\omega t') - V_y \cos(\omega t')\right]. \qquad (22)$$

We will take into account that the Lorentz force components in (22), containing c^2 in the denominator, can be excluded from calculation because they are much less than the components without the speed of light. From the ratio of these components the condition follows: $\omega |z| V_z < c^2$. The velocity of praons V_z along the axis OZ reaches almost the speed of light, so that the condition has the form $\omega |z| < c$, which corresponds to the previously accepted expression $\omega r' < c$ for the near zone. Consequently, an approximate solution to the equations (22) for the particles' velocity has the form:

$$V_x \approx -\frac{e e_{pr} R_0}{4\pi\varepsilon_0 \gamma m_{pre} r'^3 \omega}\sin(\omega t'), \qquad V_y \approx \frac{e e_{pr} R_0}{4\pi\varepsilon_0 \gamma m_{pre} r'^3 \omega}\cos(\omega t'), \qquad V_z \approx const.$$

What would change, if at these velocities we will take into account that the electric field components (19) also contain constant terms, containing the multiplier $Z-1$? If the action of the field component E_z can be neglected, then taking into account the constant terms in the components E_x and E_y leads to emerging of an additional centripetal force. This force influences the negative praons and changes their velocity on the stable rotation trajectory up to the following values:

$$V_x \approx -\frac{ee_{pr}\omega R_0 \sin(\omega t')}{4\pi\varepsilon_0\gamma\, m_{pre} r'^3\omega^2 - ee_{pr}(Z-1)}, \qquad V_y \approx \frac{ee_{pr}\omega R_0 \cos(\omega t')}{4\pi\varepsilon_0\gamma\, m_{pre} r'^3\omega^2 - ee_{pr}(Z-1)}, \qquad V_z \approx const\,. \tag{23}$$

For the hydrogen atom $Z=1$ and the expressions for velocities are simplified. In this case, from (23) we see that in the near zone at the time t', which does not exceed the period of the electron's rotation around the nucleus, the negative praons rotate around the axis OZ at velocity $\mathbf{V}_{pre}$ following the electron's rotation in the atom. For the positive praons, at the same angular velocity vector, the linear velocity components in (23) will be in opposite direction relative to the velocity components of the negative praons, due to a different sign of charge. For such motion, it is enough for the negative praons to rotate on the same side as the electron at the early time and for the positive praons to be on the opposite side relative to the axis OZ, at equal common rotation. We can also take into account that the negative praons at their matter level are the analogues of electrons and therefore the mass ratio of positive and negative praons is equal to the mass ratio of proton and electron: $\frac{m_{pr}}{m_{pre}} = \frac{m_p}{m_e}$. Substituting m_{pr} instead of m_{pre} in (23) leads to the fact that the velocities and radii of rotation of the positive praons will be significantly less than those of the negative praons.

Figure 1 shows a surface perpendicular to the axis OZ and shifted along this axis for a certain distance from the atom, on which we can see the directions of the electric and magnetic fields (20) and the velocities of praons according to (23) for the hydrogen atom at $Z=1$. All vectors correspond to the time point t', at which the condition $\omega t' = 2\pi n$ is met, where $n = 1, 2, 3....$.

The vector $\mathbf{V}_{pr}$ stands for the velocity of the positive praons.

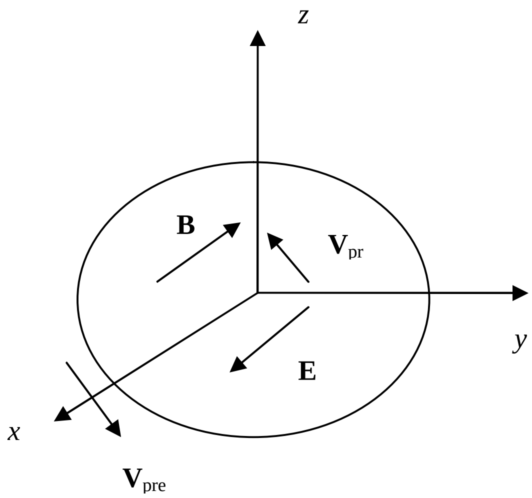

Fig. 1. The fields (20) and velocities (23) of praons close to the axis OZ in the near zone at $\mu t' = 2® n$ for the hydrogen atom.

4.2. The wave zone

Let us now consider another extreme case, when the coordinate z is in the remote wave zone. Here the properties of the emerging photon should reveal themselves to the full extent. If we consider the electric field strength components in (17), we see that among all the terms those terms become the maximum terms, which contain the square of the speed of light. These terms slowly decrease with the distance, because they contain the distance r' to the first power in the denominator. In the magnetic components, the largest terms also slowly decrease with the distance, since they are proportional to the multiplier $\frac{z}{r'^2}$.

Turning again to the hydrogen atom, we will replace q in (17) with the electron's negative charge $-e$ and will add to (17) the components of the static electric field from the charge $+Ze$ of the atomic nucleus, located in the center of the coordinate system. As a result, the field components in the wave zone can be expressed as follows:

$$E_x = \frac{(Z-1)ex}{4\pi\varepsilon_0 r'^3} - \frac{e\omega^2 R_0 \cos\omega t'}{4\pi\varepsilon_0 r' c^2}, \quad E_y = \frac{(Z-1)ey}{4\pi\varepsilon_0 r'^3} - \frac{e\omega^2 R_0 \sin\omega t'}{4\pi\varepsilon_0 r' c^2}, \quad E_z = \frac{(Z-1)ez}{4\pi\varepsilon_0 r'^3}. \qquad (24)$$

$$B_x = \frac{e\omega^2 R_0 z \sin\omega t'}{4\pi\varepsilon_0 r'^2 c^3}, \quad B_y = -\frac{e\omega^2 R_0 z \cos\omega t'}{4\pi\varepsilon_0 r'^2 c^3}, \quad B_z = -\frac{e\omega^2 R_0}{4\pi\varepsilon_0 r'^2 c^3}\left(x \sin\omega t' - y\cos\omega t'\right) \approx 0.$$

We will consider sufficiently long distances r', when the conditions $\omega r' > c\sqrt{\frac{(Z-1)|x|}{R_0}}$, $\omega r' > c\sqrt{\frac{(Z-1)|y|}{R_0}}$ are met. Then in the components E_x and E_y in (24) we can neglect the constant terms from the nuclear field. As for component E_z, it should have little effect on the photon's motion also due to its electrical neutrality.

The magnetic field component B_z as compared with the components B_x and B_y is small. For example, the amplitude ratio of the components B_z and B_x at small x and y is estimated as $\frac{B_z}{B_x} \approx \frac{|x|}{|z|} \approx \frac{R_0}{|z|} \ll 1$. Further on we will consider that the component B_z is close to zero and in the wave zone it is not involved in the processes inside the photon. Then the electric and magnetic fields that remain in (24) would be perpendicular to each other and to the axis OZ, besides the magnetic field components would be shifted forward relative to the electric field components at an angle $\pi/2$ and rotate at the same frequency ω. In addition, the relation $E_x = cB_y$ appears. In a photon the same conditions are met, and it is expected that the fields in the form of (24) should form a circularly polarized photon, that is, with rotation of the electric vector relative to the photon's axis.

In (24) we will turn from the earlier time t' to the current time t in the laboratory reference frame, taking into account the definition: $t' = t - \frac{r'}{c}$. We will also introduce the wave vector with the amplitude $k=\frac{2\text{®}}{\text{a}}=\frac{\mu}{c}$, which is directed along the axis OZ, so that at any sign of the coordinate z and velocity of praons V_z the following relations are satisfied: $kz>0$, $kV_z>0$. Then $\mu t'=\mu t-\frac{\mu r'}{c}\approx\mu t-\frac{\mu|z|}{c}=\mu t-kz$, and for periodically varying fields we can write the following:

$$\cos\mu t'=\cos(\mu t-kz)\,,\qquad \sin\mu t'=\sin(\mu t-kz)\,,\qquad \hat{\mathbf{R}}_E=[\cos(\mu t-kz),\sin(\mu t-kz),0],$$

$$\hat{\mathbf{R}}_B=[-\sin(\mu t-kz),\cos(\mu t-kz),0],\qquad \mathbf{E}_\perp\approx-\frac{e\mu^2R_0}{4\text{®}\text{£}_0 r'c^2}\hat{\mathbf{R}}_E\,,\qquad \mathbf{B}_\perp\approx-\frac{e\mu^2 zR_0}{4\text{®}\text{£}_0 r'^2c^3}\hat{\mathbf{R}}_B\,. \tag{25}$$

As we can see, at any constant value $r'\approx|z|$, the fields in (25) depend on the time according to the sine law. In addition, as the coordinate z increases at the points, where the condition $z=n\text{a}$ is satisfied and $n=1,2,3...$, the fields (25) rotate synchronously with each other along the axis OZ. Thus, the field acquires a periodic spatial structure, repeated after a minimum distance equal to the wavelength. In the previous case, when equation (21) was solved, the spatial structure was not considered, as we were considering the near zone, the size of which is of the order of less than one wavelength.

Similarly to (21), we will write the equation of motion for the negative praons, but with respect to the current time t:

$$m_{pre}\frac{d}{dt}(\text{¥}\mathbf{V})=-e_{pr}\mathbf{E}-e_{pr}\left[\mathbf{V}\times\mathbf{B}\right].$$

After substituting the fields (25) into this equation we obtain:

$$\frac{d}{dt}(¥V_x)=\frac{\partial}{\partial t}(¥V_x)+\mathbf{V}\cdot\nabla(¥V_x)=\frac{ee_{pr}µ^2R_0}{4®£_0 m_{pre}r'c^2}\cos(µt-kz)\left(1-\frac{zV_z}{r'c}\right), \qquad (26)$$

$$\frac{d}{dt}(¥V_y)=\frac{\partial}{\partial t}(¥V_y)+\mathbf{V}\cdot\nabla(¥V_y)=\frac{ee_{pr}µ^2R_0}{4®£_0 m_{pre}r'c^2}\sin(µt-kz)\left(1-\frac{zV_z}{r'c}\right),$$

$$\frac{d}{dt}(¥V_z)=\frac{\partial}{\partial t}(¥V_z)+\mathbf{V}\cdot\nabla(¥V_z)=\frac{ee_{pr}µ^2zR_0}{4®£_0 m_{pre}r'^2c^3}\left[V_x\cos(µt-kz)+V_y\sin(µt-kz)\right].$$

In the right side of (26) the Lorentz force depends on two variables – the time t and the coordinate z that define the distance to the emitting atom. Therefore, during the motion of the charged particles in the electromagnetic field, the acceleration and velocity of the particles also become the functions of t and z. Due to this, we presented the time derivatives in the left side of (26) as material derivatives.

The change of z has a more significant impact on the argument of sines and cosines than the change of r' in the amplitude's denominator. If we consider z as a variable only in the sines and cosines, then the approximate solution of equations (26) for the velocity of the particles has the form:

$$V_x\approx\frac{ee_{pr}µR_0}{4®£_0¥m_{pre}r'c^2}\sin(µt-kz), \qquad V_y\approx-\frac{ee_{pr}µR_0}{4®£_0¥m_{pre}r'c^2}\cos(µt-kz), \quad V_z\approx const. \qquad (27)$$

If the time t is fixed, then in case of changing the position of the coordinate from $z=nª$ to $z=(n+1)ª$, the velocity vector in (27) will make complete revolution around the axis OZ, while at large n the decrease of the velocity amplitude due to the change of r' will be little. This proves our approximate solution of (27), though solving the equations we have not taken into account the change of z in r' in the denominator of the Lorentz force's amplitude.

Figure 2 shows a surface perpendicular to the axis OZ, where the directions of the electric and magnetic fields (25) and praons' velocities are shown according to (27). The vectors $\mathbf{V}_{pr}$ and $\mathbf{V}_{pre}$ denote the velocities of the positive and negative praons, respectively.

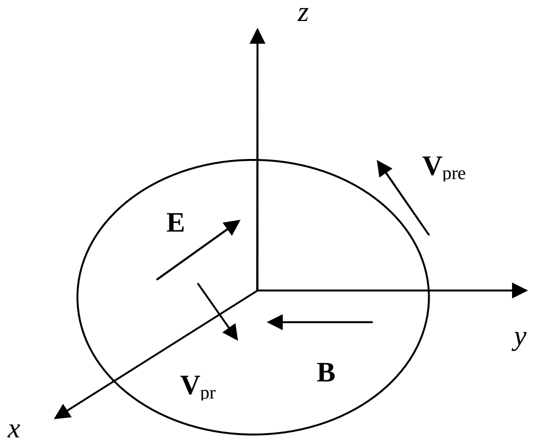

Fig. 2. The fields (25) and velocities (27) of the praons near the axis OZ in the remote wave zone at $\mu t' = 2® n$.

Let us pay attention to the difference between the solutions (23) and (27), which consists in the fact that the praons' velocities in them for the hydrogen atom at $Z = 1$ have different signs. In this case, at the boundary between the near and wave zones, which is reflected by the condition $\mu r' \approx c$, a change of the field action takes place. Specifically, the total field of the electron changes its phase to the opposite, due to the increased field components (25) in comparison with the field components (20). As a result, when the electron is rotating on the one side from the axis OZ, the negative praons are located and rotating under the field action on the opposite side of the axis OZ. As for the positive praons, they are now located on the side, where the electron is moving, and are rotating at lower speed and with a smaller radius of rotation, due to their large mass.

Additionally, the photon obtains spatial structure in the wave zone. How can it be explained from the standpoint of physics? Assume that the electromagnetic field of the electron, which is periodically varying in the course of rotation, achieves a certain cross section of the photon at a distance z_1 from the atom and sets its particles into motion. Then, the electron makes a revolution inside the atom, and at this point new particles come to the cross section at z_1 from the side of the atom. The electron exerts influence on them by its field, as in the previous case, and everything is repeated. The same holds true for the points with coordinates $z_1 + n\lambda$, where the field comes from the electron in the same phase and respectively it was emitted by the electron at the earlier time points. Since the beginning of the photon's emission, as the time was passing and the number of the electron's revolutions was increasing, the number of single-phase points with coordinates $z_1 + n\lambda$ was increasing until the rotating field of the electron would not cover the entire area that should be occupied by the photon. Besides, if the motion of particles inside the photon occurs in a certain way and synchronously with the electron's motion, as in (27), then it creates the necessary conditions for the wave structure inside the photon, which is periodically varying in space and time.

The velocity components $\mathbf{V}$ in (27) are recorded in the reference frame K, associated with the atom emitting the photon. Let us now turn to the reference frame K', which is moving along the axis OZ at the velocity V_z almost reaching the speed of light. For this purpose we will use the direct Lorentz transformations as follows:

$$\tau' = \frac{t - V_z z / c^2}{\sqrt{1 - V_z^2 / c^2}}, \qquad z' = \frac{z - V_z t}{\sqrt{1 - V_z^2 / c^2}}, \qquad x' = x, \qquad y' = y, \quad \omega t - k z = \omega' \tau' - k' z'. \tag{28}$$

In K' we denoted the proper time with τ', to avoid confusion with the earlier time t' in (20). We also would need to transform the velocities, that is to establish relation between the velocities in both reference frames. In this case, we obtain the following:

$$V'_x = \frac{V_x}{\sqrt{1 - V_z^2/c^2}}, \qquad V'_y = \frac{V_y}{\sqrt{1 - V_z^2/c^2}}, \qquad V'_z = 0,$$

$$\frac{1}{\gamma'} = \sqrt{1 - V'^2/c^2} = \frac{\sqrt{1 - V^2/c^2}}{\sqrt{1 - V_z^2/c^2}} = \frac{1}{\gamma\sqrt{1 - V_z^2/c^2}}. \tag{29}$$

The velocity V' denotes the full velocity of the particle in K', and γ' is the Lorentz factor of the particle in K'. Let us substitute into (27) the Lorentz transformation for the wave phase (28) and the transformation (29) of the velocities and the Lorentz factor, leaving r' in the velocity's amplitude constant and expressed in terms of the coordinates in K:

$$V'_x \approx \frac{e e_{pr} \omega R_0}{4\pi\varepsilon_0 \gamma' m_{pre} r' c^2} \sin(\omega' t' - k' z'), \qquad V'_y \approx -\frac{e e_{pr} \omega R_0}{4\pi\varepsilon_0 \gamma' m_{pre} r' c^2} \cos(\omega' t' - k' z'). \tag{30}$$

As is known, the role of the Lorentz transformations reduces to establishing the relation between the clock values and the coordinates of events in the inertial reference frames. It follows from them that in the moving reference frames the rate of clock slows down. In (30), in the reference frame K', in view of the relation $\omega = ck$ and the inverse Lorentz transformations in the wave phase (28), the role of the angular rate of rotation of the velocity vector is played by the quantity $\omega' = \frac{\omega - kV_z}{\sqrt{1 - V_z^2/c^2}} = \frac{\omega(1 - V_z/c)}{\sqrt{1 - V_z^2/c^2}}$. The angular velocity ω' is less than the angular velocity of rotation ω of the electron in the atom and the angular frequency of the photon due to the time dilation effect. At the same time, in K' the wave vector $k' = \frac{k - \omega V_z/c^2}{\sqrt{1 - V_z^2/c^2}} = \frac{k(1 - V_z/c)}{\sqrt{1 - V_z^2/c^2}}$ becomes smaller and the wavelength $\lambda' = \frac{2\pi}{k'}$ becomes larger, which is due to the effect of reduction of the longitudinal dimensions of the moving bodies in K.

According to (30), in the reference frame K' we observe rotation of the negative praons at the angular velocity ω' in the plane $X'O'Y'$, and in case of instantaneous motion of the observer along the axis $O'Z'$ with changing of z' we discover displacement of the rotation phase by the value $\Delta\varphi = -k'z'$. For this to happen the particles inside the photon must be arranged as if they are located on the surface of the right-threaded screw with the pitch $d' = \frac{2\pi}{k'} = \lambda'$, while the screw is rotating to the right at the angular velocity ω', without moving along the axis $O'Z'$. If we consider the positive praons as the rotating particle inside the photon, then due to their increased mass, their rotation velocity in (30) would be less. The positive praons can be placed on the surface of the screw, the radius of which is $\frac{m_p}{m_e}$ times less than the radius of the screw for the negative praons. At each time point the positive praons would be on the same side as the electron at a corresponding delayed time t', while the negative praons would be located on the other side of the axis $O'Z'$.

4.3. The second field component

Let us consider the action of the second field component in (17) on the motion of the particles inside the photon in the wave zone. The field of this component at $q = -e$ in view of the electric field of the nucleus is as follows:

$$E_x = \frac{(Z-1)ex}{4\pi\varepsilon_0 r'^3} - \frac{e\omega R_0 \sin\omega t'}{4\pi\varepsilon_0 r'^2 c}, \qquad E_y = \frac{(Z-1)ey}{4\pi\varepsilon_0 r'^3} + \frac{e\omega R_0 \cos\omega t'}{4\pi\varepsilon_0 r'^2 c}, \qquad E_z = \frac{(Z-1)ez}{4\pi\varepsilon_0 r'^3}. \tag{31}$$

$$B_x = -\frac{e\omega R_0 z\cos\omega t'}{4\pi\varepsilon_0 r'^3 c^2}, \qquad B_y = -\frac{e\omega R_0 z\sin\omega t'}{4\pi\varepsilon_0 r'^3 c^2}, \qquad B_z = -\frac{e\omega R_0 \left(R_0 - x\cos\omega t' - y\sin\omega t'\right)}{4\pi\varepsilon_0 r'^3 c^2}.$$

Under conditions $\mu r' > \frac{c(Z-1)|x|}{R_0}$, $\mu r' > \frac{c(Z-1)|y|}{R_0}$, in the electric field components in (31) we can neglect the constant terms from the nuclear field including $Z-1$. Additionally, we can also neglect the magnetic field component B_z, since it would be $|z|/R_0$ times less than the components B_x and B_y. In (31) let us turn from the early time point t' to the current time point t, taking into account the definition: $\mu t' = \mu t - kz$. At $k = \frac{2®}{a} = \frac{\mu}{c}$ we find:

$$\sin \mu t' = \sin(\mu t - kz), \qquad \cos \mu t' = \cos(\mu t - kz), \qquad \hat{\mathbf{R}}_E = [-\sin(\mu t - kz), \cos(\mu t - kz), 0],$$

$$\hat{\mathbf{R}}_B = [\cos(\mu t - kz), \sin(\mu t - kz), 0], \qquad \mathbf{E}_\perp \approx \frac{e\mu R_0}{4®£_0 r'^2 c}\hat{\mathbf{R}}_E, \qquad \mathbf{B}_\perp \approx -\frac{e\mu R_0 z}{4®£_0 r'^3 c^2}\hat{\mathbf{R}}_B. \tag{32}$$

Doing the same as in the previous section, similarly to (26) we obtain the following:

$$\frac{d}{dt}(¥V_x) = \frac{\partial}{\partial t}(¥V_x) + \mathbf{V}\cdot\nabla(¥V_x) = \frac{ee_{pr}\mu R_0}{4®£_0 m_{pre} r'^2 c}\sin(\mu t - kz)\left(1 - \frac{zV_z}{r'c}\right),$$

$$\frac{d}{dt}(¥V_y) = \frac{\partial}{\partial t}(¥V_y) + \mathbf{V}\cdot\nabla(¥V_y) = -\frac{ee_{pr}\mu R_0}{4®£_0 m_{pre} r'^2 c}\cos(\mu t - kz)\left(1 - \frac{zV_z}{r'c}\right),$$

$$\frac{d}{dt}(¥V_z) = \frac{\partial}{\partial t}(¥V_z) + \mathbf{V}\cdot\nabla(¥V_z) = \frac{ee_{pr}\mu R_0 z}{4®£_0 m_{pre} r'^3 c^2}\left[V_x \sin(\mu t - kz) - V_y \cos(\mu t - kz)\right].$$

The approximate solution of these equations for the velocity of particles has the form:

$$V_x \approx -\frac{e e_{pr} R_0}{4\pi\varepsilon_0 \gamma\, m_{pre}\, r'^2 c}\cos(\omega t - kz)\,, \quad V_y \approx \frac{e e_{pr} R_0}{4\pi\varepsilon_0 \gamma\, m_{pre}\, r'^2 c}\sin(\omega t - kz)\,, \quad V_z \approx const\,. \quad (33)$$

Figure 3 shows the surface perpendicular to the axis OZ, on which the directions of the electric and magnetic fields (32) and the velocities of praons are shown, according to (33). All the vectors correspond to the time point t', at which the condition $\omega t' = 2\pi n$ is met. The vectors $\mathbf{V}_{pr}$ and $\mathbf{V}_{pre}$ denote the velocities of the positive and negative praons, respectively.

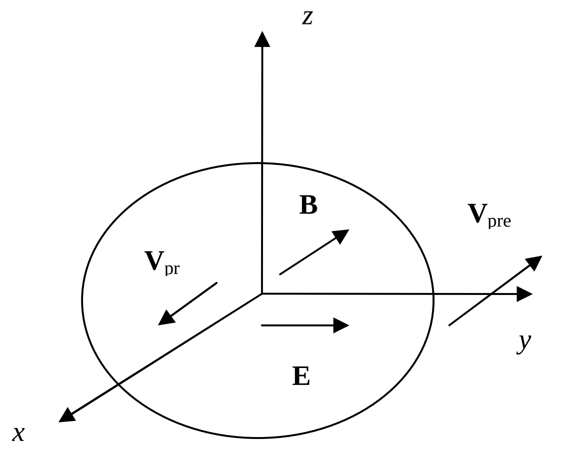

Fig. 3. The fields (32) and velocities (33) of praons near the axis OZ in the wave zone at $\omega t' = 2\pi n$.

5. THE PHOTON STRUCTURE

The presence of r' in the denominator of the velocity in (23) for the near zone and in (27) for the wave zone leads to decreasing of the velocity amplitude while the distance from the emitting atom is increasing. Obviously, for the photon to exist independently at a certain distance from the atom, the amplitude of the rotation velocity of the negatively charged praons in the photon must stop being dependent on r'. By analogy with (20) and (25), in which we will replace r' with a certain constant distance z_0, we will assume the following expressions for the amplitude of the electric field inside the photon in the near zone and in the wave zone, respectively:

$$E_1 = \frac{eR_0}{4\pi\varepsilon_0 z_0^3}, \qquad E_3 = \frac{e\omega^2 R_0}{4\pi\varepsilon_0 z_0 c^2}.$$

We have an opportunity to estimate the value of z_0 using the data from [14] for the photon with the angular frequency $\omega = 1.54946 \cdot 10^{16}$ s^{-1}, which emerges in the hydrogen atom in the electron's transition from the second to the first level in the Lyman series, setting the photon radius equal to $R_0 = 4a_B$. Based on the photon energy and its volume, with equality of the density of this energy and the electromagnetic energy density, we determine the amplitude of the electric field inside the photon: $E_0 = 2.1 \cdot 10^6$ V/m.

If we equate E_1 and E_0, we obtain $z_0 = 99a_B$, where a_B is the Bohr radius. However, if we equate E_3 and E_0, then we should obtain $z_0 = 7a_B$. In the near zone the field E_3 is substantially smaller than the field E_1, and therefore, only at a small distance from the nucleus of the order of $7a_B$, the field E_3 could set the photon's praons in motion so that it could have a field of the order of E_0. At the boundary between the near and wave zones, which is reflected by the condition $\omega z \approx c$, the value $z = 366a_B$. Consequently, the internal electromagnetic energy of the photon, associated with the motion of the charged particles in it, appears in it already in the near zone. Here, the particles of the emerging photon are influenced by the electric field (17), consisting of three main components, which get aligned with each other at $\omega z \approx c$ and the value $z = 366a_B$.

The amplitude of the transverse electric field of the second component in (17), according to (32), at $r' \approx z = z_0$ is equal to $E_2 = \frac{e\omega R_0}{4\pi\varepsilon_0 z_0^2 c}$. From the equality $E_2 = E_0$ we obtain the estimate: $z_0 = 52a_B$, so that in the near zone the second component in (17) has lower degree of influence on the particles inside the photon than the first component, but its influence is stronger than that of the third field component.

Analyzing the field directions and the velocities of particles in Figures 1-3, resulting from the field components (17), in a first approximation we can develop the photon model, which is symmetric in its form. The photon's cross section at $\mu t' = 2\circledR n$ in this model is presented in Figure 4.

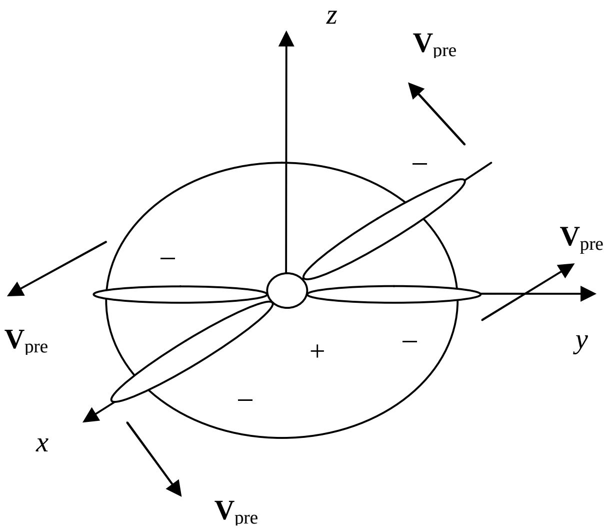

Fig. 4. The photon's cross section at $\mu t' = 2\circledR n$. The positive charge near the axis OZ is indicated with $+$, the negative charges of the lobes are indicated with $-$.

When the rotation phase of the electron in the atom satisfies the relation $\mu t' = 2\circledR n = \mu t - kz$, where t' is the earlier time point, then for any time point t we can choose such z, with which the pattern of events will be repeated in the same way as in Figure 4. In this case in Figure 4 the lobes along the axis OX are formed by the negative praons under action of the fields of the form (20) and (25), as in Figures 1 and 2, respectively. In Figure 4, we also added the lobes of the negative praons that are likely to occur under action of the fields (32), as in Figure 3. In the center, near the axis OZ the positive praons are concentrated. The whole lobes' construction is rotating around the axis OZ at the angular velocity μ and it is also moving along this axis at the velocity V_z, which is almost equal to the speed of light. At a given time point t with the change z the phase $\mu t - kz$ would change and other lobes would appear in the new cross section of the photon, which would be shifted relative to the lobes in Figure 4 at a corresponding angle. This means that the entire set of lobes of the negative praons form continuous helical lines in space at a pitch equal to the wavelength and with the length along the axis OZ equal to the photon's length.

In this case we can expect that at $z_0 = 7a_B$ formation of the two corresponding lobes stops and they become independent of the field E_3, which is decreasing in amplitude. For the rest of the lobes the same is true at $z_0 = 52a_B$ for the field E_2 and at $z_0 = 99a_B$ for the field E_1. Although these estimates are not entirely accurate, as we assumed the constancy of r' in the denominator of the solutions for the praons' velocities (23), (27) and (33), the general result remains the same: the electric field of the rotating electron cloud is able to create the lobe structure of the emerging photon. The lobes arising from praons are then fixed by the forces acting between the praons.

Theoretically, inside each lobe in Figure 4 there should be sufficiently smooth distribution of the charge, from the positive charge at the center – to the prevalence of the negative charge at the edges of the lobes. This should also be accompanied by smooth change of the mass density along the lobes. In this case, the lobes contain not only the negative praons but also a significant number of positive praons. We compare the positive praons with protons and the negative praons with electrons, and admit the existence of neutral praons as the analogues of neutrons.

From the solutions for the velocities of praons (23), (27) and (33) we see that these velocities in a first approximation do not depend on whether the photon is propagating in the positive or negative direction of the axis OZ. These solutions do not contradict the fact that in quantum transition two photons will be simultaneously emitted from the atom in opposite directions. These photons must have oppositely directed circular polarization, that is, have different rotation directions of the electric vector with respect to the velocity of the photon.

However, as a rule, except for the special cases of excitation, a multielectron atom emits one photon. To explain this, let us turn to the results in [9], where the substantial model of electron was presented, which was understood not as a charged point, but as a three-dimensional structure in the form of an electron disk. It is assumed that the matter in the disk rotates differentially around the disk's center at the angular velocity $\mu_1(r_1)$, which depends on the current radius r_1 of the matter unit's location. In addition, the disk's center can be located at a distance r_2 from the nucleus and rotate around it at the angular velocity μ_2. The latter allows us to explain the electron spin as the result of rotation of the electron disk as a whole around the nucleus, as well as to ensure the possibility of electromagnetic emission from the atom, while there is rotation at the angular velocity μ_2. In [9] we take into account that the negatively charged matter of the electron cloud is attracted to the positively charged nucleus and at the same time repels from itself by electrical forces. In this model, the matter is also under influence of the strong gravitation from the nucleus with the strong gravitational constant $G_a = 1.514 \cdot 10^{29}$ $m^3 \cdot kg^{-1} \cdot s^{-2}$. The sum of all these forces makes the electron matter rotate around the nucleus. The stable quantized states of the atom's energy are explained by the fact that in these states the equality is achieved of the kinetic energy flux of the electron matter and of the sum of the fluxes of the electromagnetic and gravitational energies in this matter. Besides, the emission from the atom tends to zero and the state of the electron disk's rotation remains unchanged for a long time and the field momentum is not transferred to the matter.

In the substantial model of the electron it is important that in the multielectron atom the electron disks are located in the atomic shells approximately parallel to each other and the number of electrons in each filled shell is even. This leads to the fact that the magnetic energy of the atom tends to a minimum, since the magnetic moments of the respective paired electrons are directed oppositely (the Pauli exclusion principle). To explain the Pauli principle the well-known Lenz rule is used: as the magnetic field in the conductor increases, the magnetic field is formed which opposes the initial magnetic field. If an atom has an unpaired electron and is combined with a free electron, the latter will have such a rotation of the disk's matter as to create a magnetic field, according to the Lenz rule and to the Pauli principle. This explanation does not require any reference to the quantum spins of the electrons and is based on the known electromagnetic phenomena.

For the maximum number of electrons in the electron shell of the atom there is a quadratic dependence $2n^2$. As for the multiplier 2 before n^2, we believe that this is a consequence of the Pauli principle, as well as of the symmetry in the arrangement of electrons in the form of rings-disks. As for the quadratic dependence n^2, we can see that as the shell's number n increases the distance to this shell increases too. The shell's area like the sphere's area varies in proportion to the squared distance. Therefore, in case of a corresponding change of the distance to the shell with the number n, the relative density of electrons as the number of electrons per unit area of the shell, remains unchanged. Only in this case, the entire matter of each electron will be located on the shell with the same density, and the total charges and masses of the electrons on the shells will be integer-valued.

Now let us consider the simplest case, when there are two paired electrons in the form of two parallel disks, one of them is an excited electron in the state of quantum transition, the momentum of which decreases with emission of a photon. We see that the situation for the two opposite fluxes of praons passing through the disk of the excited electron is asymmetric: one flux of praons passes through the first electron and then through the second excited electron. The other flux of praons first passes through the second electron and then through the first electron. Since the first electron is not excited, the center of its disk is not shifted with respect to the nucleus and does not rotate, the electron does not emit, and it influences the flux of praons only by its stationary fields. This results in a slight shift of the flux of praons, which then interacts with the matter and fields of the excited electron, and becomes involved in the formation of a photon in the propagation direction of the flux of praons. The opposite flux of praons first passes through the disk of the excited electron, and transverse rotation of praons emerges in this flux, which is necessary for a photon. But then the flux passes through the disk of the second electron, where the transverse rotation of praons is suppressed by the action of the electron's rotating charged matter, which hinders the formation of a photon in this direction. For the atomic shell, where the number of electrons is more than two, the situation gets more complicated, but does not change fundamentally – in order to emit the photon from the atom mainly in one direction, asymmetry of the excited electron's position with respect to other electrons is needed.

6. THE FIELDS INSIDE THE PHOTON

We should note that the charged praons themselves cannot generate such an electromagnetic field inside the photon so that this field in turn could lead to the required motion of particles and hold them together. For such motion of praons there should either an additional external force, for example the electromagnetic Lorentz force in (26) from the field of the rotating electron in the atom, or some internal non-electromagnetic force. For the praons inside the photon we suppose the action of strong gravitation [14], which should act between the positively charged praons in the photon's core and the negatively charged praons in the lobes. The other two forces are the electromagnetic force of attraction between the oppositely charged praons in the photon's core and in the lobes of the photon and the electromagnetic force of repulsion of the negative praons from each other. The praons in the lobes are in the state of continuous rotation, so that we must also take into account the centripetal force.

Earlier we derived the strong gravitational constant G_a for the level of atoms, equating the magnitude of all the four above-mentioned forces, acting on the electron's matter in the hydrogen atom [9], [12]. Let us assume in a first approximation that the same condition of the forces' equality holds for the praons inside the photon in the reference frame K', associated with the photon. Let us represent any of the lobes in the form of a capacitor, one plate of which is positively charged and is located at the axis OZ, and the other plate is negatively charged and is located at the end of lobe. We believe that the photon is neutral in general and the number of positively and negatively charged praons in it is equal. The capacitor plates are attracted to each other by the electric force, as well as by the attraction force of the strong gravitation:

$$F_e = QE = \frac{Q^2}{\pounds_0 A}, \qquad F_g = \frac{M\, m_{pre}\, \mathrm{d}}{m_{pr}} = \frac{4 \text{®}\, G_{pr} M^2 m_{pre}}{A m_{pr}},$$

where Q and M are the charge and mass of the positive praons on the capacitor plate, which is adjacent to the axis OZ; the product $\frac{M\,m_{pre}}{m_{pr}}$ is the total mass of the negative praons on the other capacitor plate at the end of the lobe; m_{pre} and m_{pr} set the masses of the positive and negative praons;

$E=\frac{Q}{\varepsilon_0 A}$ and $\Gamma=\frac{4\pi G_{pr}M}{A}$ are the electric filed strength and the gravitational field strength, respectively, which are acting on the plate with the negative praons, A denotes the area of the capacitor plate.

From the equality of the forces F_e and F_g , as well as the condition $\frac{Q}{M}=\frac{e_{pr}}{m_{pr}}$, we find:

$$G_{pr}=\frac{e_{pr}^2}{4\pi\varepsilon_0 m_{pr}\,m_{pre}}. \qquad (34)$$

The charge and mass of the positive praon were found in [14], using the theory of dimensions and the coefficients of similarity between the atomic and praon levels of matter: $e_{pr}=\frac{e}{S\sqrt{\Phi P}}=4.6\cdot 10^{-57}$ C, $m_{pr}=\frac{m_p}{\Phi}=1\cdot 10^{-84}$ kg, here we used the coefficients of similarity in mass $\Phi=1.62\cdot 10^{57}$, in sizes $P=1.4\cdot 10^{19}$ and in speed of processes $S=0.23$. Substituting the praon's charge and mass in (34), in view of the relations $\frac{m_{pr}}{m_{pre}}=\frac{m_p}{m_e}$, $m_{pre}=\frac{m_e}{\Phi}$, we obtain an estimate of the strong gravitational constant: $G_{pr}=3.3\cdot 10^{68}$ m$^3\cdot$kg$^{-1}\cdot$s^{-2}. On the other hand, the gravitational constants at the stellar, atomic and praon levels of matter, according to the theory of dimensions, are related to each other by the similarity coefficients:

$$G_a = \frac{\Phi}{PS^2} G = 1.514 \cdot 10^{29} \ \text{m}^3 \cdot \text{kg}^{-1} \cdot \text{s}^{-2}, \qquad G_{pr} = \frac{\Phi}{PS^2} G_a = 3.3 \cdot 10^{68} \ \text{m}^3 \cdot \text{kg}^{-1} \cdot \text{s}^{-2},$$

besides, for the strong gravitational constant at the level of atoms, the following relation from [12] holds true, which coincides by its sense with (34):

$$G_a = \frac{e^2}{4\pi\varepsilon_0 m_p m_e}.$$

The strong gravitational constant G_a allowed us not only to describe the stability of electrons in the atom, but also to explain the nature of the rest energy of elementary particles, to derive a formula for the magnetic moment of the proton [9] and to calculate its radius [18]. The stability of nucleons in the atomic nucleus is also explained, in this case the strong gravitational attraction between the nucleons is opposed by the repulsive force of the torsion fields of the strong gravitation of nucleons (the spin-spin interaction in the gravitational model of strong interaction). The coupling constant of strong gravitation is close in value to the standard coupling constant of strong interaction. In [15] it is shown that the strong gravitation structure is the same as that of the ordinary gravitation, and the range of the strong gravitation's action in the matter, which has the same mass density as that of the Earth, is not more than 0.7 m [9].

Thus it can be stated that the strong gravitation at the level of praons and the electromagnetic forces are able to keep the positive and negative praons inside the photon near each other and to ensure the photon's integrity. As for the stability of the positive praons concentrated mainly in the photon's core, here the main forces are the gravitational forces of attraction and the forces of praons' repulsion from each other, according to the gravitational model of strong interaction [9]. In this model, the gravitational force is opposed by the spin forces from the gravitational torsion field, which in particular ensures the stability of the atomic nuclei.

In Figure (4) the electric field inside the lobes is directed outwardly from the axis OZ. In the photon in addition to the electric field there must be a magnetic field perpendicular to the electric field. In order to understand how this magnetic field appears, we will consider the rotation of the photon's lobes in Figure 4 from the perspective of the reference frame K', as in Section 4.2. This reference frame is moving along the axis OZ at the same velocity V_z as the photon in the reference frame K. Taking into account (29), in K' in each cross section of the photon the lobes rotate around the axis $O'Z'$ at the angular velocity:

$$\mu' = \frac{\mu - kV_z}{\sqrt{1-V_z^2/c^2}} = \frac{\mu\left(1-V_z/c\right)}{\sqrt{1-V_z^2/c^2}} = \frac{\mu\sqrt{1-V_z^2/c^2}}{1+V_z/c} \approx \frac{\text{¥}'\mu}{2\text{¥}}. \tag{35}$$

In (35) $\text{¥}'$ denotes the Lorentz factor close to 1 for the praons in the reference frame K', and ¥ is a very large Lorentz factor for the praons in the reference frame K, in which the full velocity V and the velocity V_z of the praons are close to the speed of light. In [14] an estimate of the Lorentz factor for the praons in the photon was made: $\text{¥} = 1.9 \cdot 10^{11}$. The value μ' is substantially less than μ, which characterizes the effect of time dilation. Inside the lobes a certain electric field E' is acting, which is in equilibrium with the strong gravitational field strength and maintains the form of the lobes in view of their rotation.

Let us consider the transformation of the electromagnetic field of the lobes from the reference frame K' into the reference frame K. The electromagnetic field components are the components of the electromagnetic field tensor and therefore they can be transformed from one inertial reference frame into another not as the components of a four-vector, but as the components of a four-tensor. In particular, for the transformation of the field components during the motion of the reference frame K' along the axis OZ we can write:

$$E_x = \frac{E'_x + V_z B'_y}{\sqrt{1-V_z^2/c^2}}, \qquad E_y = \frac{E'_y - V_z B'_x}{\sqrt{1-V_z^2/c^2}}, \qquad E_z = E'_z, \tag{36}$$

$$B_x = \frac{B'_x - E'_y V_z / c^2}{\sqrt{1 - V_z^2 / c^2}}, \qquad B_y = \frac{B'_y + E'_x V_z / c^2}{\sqrt{1 - V_z^2 / c^2}}, \qquad B_z = B'_z .$$

The slow rotation of the negatively charged lobes creates a certain common magnetic field B'_z. Let us consider in Figure 4 one of the lobes, in which the internal electric field at a given time is directed along the axis $O'X'$ and is equal to E'_x. At this time point, other electric field components averaged with respect to the volume of the lobe are zero, $E'_y = 0$ and $E'_z = 0$, and similarly the magnetic field components $B'_y = 0$ and $B'_x = 0$. Then from (36) it follows that for the components of the lobe's field, which are averaged with respect to the volume, in the reference frame K we should obtain:

$$E_x = \frac{E'_x}{\sqrt{1 - V_z^2 / c^2}}, \qquad E_y = 0, \qquad E_z = 0, \qquad B_x = 0, \qquad B_y = \frac{E'_x V_z / c^2}{\sqrt{1 - V_z^2 / c^2}} = \frac{E_x V_z}{c^2} \approx \frac{E_x}{c},$$

$$B_z = B'_z .$$

Since $V_z \approx c$ we arrive at the condition $E_x = \frac{c^2 B_y}{V_z} \approx c B_y$, which holds in the photon and relates its electric field strength and magnetic field. Meanwhile the transverse magnetic field B_y appears as a consequence of transformation of the electromagnetic field components from the reference frame K' into the reference frame K, in which the photon is moving at the velocity V_z. At each point of the lobe under consideration in K, the magnetic field B_y appears, which is perpendicular to the electric field E_x inside this lobe.

If in Figure 4 we take another lobe, then the direction of the magnetic field, which is transverse to this lobe, would change accordingly, but it will be perpendicular to the axis of the lobe and to its internal electric field. In a first approximation, we can assume that the electric fields in the cross section of the photon in Figure 4 rotate with the lobes and are directed radially from the axis, and the magnetic field is located on the segments of circles in the places, where it crosses the lobes, and is directed along the tangents to the circle.

7. THE LORENTZ FACTOR AND ENERGY FLUXES

We will recall, as in [14] we found the charge to mass ratio and the Lorentz factor γ for the praons in the photon. Suppose some praon is located on the radius R_0 and rotates at a certain velocity V around the photon's axis. For the period of rotation of the particle we can write the following:

$$T=\frac{2\pi}{\omega}=\frac{2\pi R_0}{V}=\frac{\lambda}{c}, \qquad V=\omega R_0 .$$

The relation between the centripetal force, required to rotate the particle, and the electric force, exerted on the particle with the charge e_{pr} and the rest mass $\overline{m}$, is as follows:

$$e_{pr}E_0=\frac{\overline{m}V^2}{R_0}=\gamma\,\overline{m}\,\omega^2 R_0 . \qquad (37)$$

For the photon, it is assumed that half of its energy $W=\hbar\omega$ is the energy of the particles' rotation, and the other half of its energy is the total energy of all the fields. Besides, in the reference frame K the angular momentum of the photon is equal to the Dirac constant and is given by a formula, which corresponds to a rotating cylinder composed of N particles:

$$L_p=\hbar=\frac{1}{2}N\gamma\,\overline{m}R_0^2\omega \quad . \qquad (38)$$

Based on (38), we can estimate the energy of rotation: $W_r=\frac{1}{2}L_p\omega=\frac{1}{2}\hbar\omega=\frac{1}{2}W$.

Dividing the photon energy by the photon volume, we obtain the energy density, which can be equated to the double density ε_{em} of the electromagnetic energy inside the photon:

$$\frac{\hbar\omega}{\pi R_0^2 c^2} = 2\varepsilon_{em} = \varepsilon_0 E_0^2 . \qquad (39)$$

From (37) and (39), for the photon under consideration in view of (7) with the photon radius $R_0 = 4a_B$ and $\omega = 1.54946 \cdot 10^{16}$ s^{-1} it follows:

$$\frac{e_{pr}}{\gamma \bar{m}} = R_0^2 \sqrt{\frac{\pi \varepsilon_0 c^2 \omega^3}{\hbar}} = 2.4 \cdot 10^{16} \ \text{C/kg}. \qquad (40)$$

In Section 6, we have shown how the praon's charge and mass are calculated from the theory of similarity of matter levels with the use of similarity coefficients. If we substitute $\bar{m} = m_{pr}$ in (40), then we would find the value of the Lorentz factor $\gamma = 1.9 \cdot 10^{11}$.

For the case of a hydrogen-like atom we can see that in (40) the following proportions hold true: $^{2} \sim \frac{i^6 - j^6}{Z^4}$ according to (7), as well $R_0 \sim \frac{i^2}{Z}$ and $\omega \sim Z^2 \left(\frac{1}{j^2} - \frac{1}{i^2} \right)$. If the principal quantum numbers of the energy states i and j are large enough, and the condition $i - j = 1$ is met, then we will have $\gamma \sim \frac{Z}{i^2}$. Consequently, the Lorentz factor γ increases in proportion to the nuclear charge number Z or to the square root of the photon energy: $\gamma \sim \sqrt{\frac{W}{i}}$. The highest value γ of the photon is expected in the hydrogen-like atom, which has the nucleus with the largest number of protons, and in electron transitions near the smallest orbits. In this case the largest fields of the atom influence the praons of the emerging photon and transfer their energy to them.

From transformations of the electromagnetic field components (36) it was found that $E_x = cB_y$ in the photon. Deriving (34) we assumed that in the photon the balance is achieved between the electromagnetic force and the force from the strong gravitation, and in (37) we also took into account the equality of the electromagnetic force and the centripetal force, arising from rotation of the praons inside the photon. The full balance of the forces should also include the fourth force, arising from repulsion of the praons' charges from each other. All the four forces are approximately equal in magnitude. Let us now consider the ratio of the energy fluxes inside the photon. For the average values of the electromagnetic Poynting vector and accordingly of the gravitational Heaviside vector [12], [19], after averaging over the wave period of the periodically varying field components, we can write:

$$\langle \mathbf{S}_p \rangle = \frac{\mathbf{E}\times\mathbf{B}}{2\mu_0}, \qquad \langle S_p \rangle = \frac{EB}{2\mu_0} = \frac{E^2}{2\mu_0 c}, \qquad \langle \mathbf{H} \rangle = -\frac{c^2}{8\pi G_{pr}}\mathbf{\Gamma}\times\mathbf{\Omega},$$

$$\langle H \rangle = -\frac{c^2 \Gamma\, \Omega}{8\pi G_{pr}} = -\frac{c\Gamma^2}{8\pi G_{pr}},$$

here $\mathbf{\Omega}$ is the vector of the gravitational torsion field as the strong gravitational field component, which is similar in its meaning to the magnetic field induction, and we used the conditions of the form $E = cB$ and $\Gamma = c\,\Omega$ for the amplitudes of the field components.

Let us calculate the ratio of the amplitude of the average value of the gravitational energy flux vector to the amplitude of the average value of the electromagnetic energy flux vector. Again, we will consider the model of a lobe inside the photon in the form of a capacitor, as in derivation of (34), and will take into account the expressions for the amplitudes of the field strengths in the form: $E = \frac{Q}{\varepsilon_0 A}$ and $\Gamma = \frac{4\pi G_{pr} M}{A}$. In view of the relation $\frac{Q}{M} = \frac{e_{pr}}{m_{pr}}$ and (34) we obtain:

$$\frac{\langle H \rangle}{\langle S_p \rangle} = \frac{\text{«}_0 c^2 \text{d}^{\,2}}{4\text{®} G_{pr} E^2} = \frac{4\text{®£}_0 G_{pr}\, \text{j}^{\,2}}{Q^2} = \frac{4\text{®£}_0 G_{pr} m_{pr}^2}{e_{pr}^2} = \frac{m_{pr}}{m_{pre}} = \frac{m_p}{m_e}.$$

The ratio of the fluxes of gravitational and electromagnetic energies in the photon turns out to be equal to the ratio of the proton mass to the electron mass. This correlates with the fact that, according to [14], for each matter level the ratio of the energy density of the field of gravitons in the vacuum field, responsible for the gravitational forces, to the energy density of the charged particles in the vacuum field, responsible for the electromagnetic forces, is also equal to the ratio of the proton mass to the electron mass.

8. THE MAGNETIC DIPOLE MOMENT

The non-zero component of the magnetic field $B_z = B_z'$ inside the photon leads to the fact that the photon as a whole must have some magnetic dipole moment. Let us consider the photon in the reference frame K', where the amplitude of the wave vector and the wavelength, in view of (29), are as follows:

$$k' = \frac{k - \text{µ} V_z / c^2}{\sqrt{1 - V_z^2 / c^2}} = \frac{k(1 - V_z / c)}{\sqrt{1 - V_z^2 / c^2}} = \frac{k\sqrt{1 - V_z^2 / c^2}}{1 + V_z / c} \approx \frac{\text{¥}' k}{2\text{¥}}. \qquad \text{ª}' = \frac{2\text{®}}{k'} = \frac{4\text{®¥}}{\text{¥}' k} = \frac{2\text{¥ª}}{\text{¥}'}. \tag{41}$$

To estimate the magnetic field we will represent the photon in the reference frame K' in the form of a solenoid with the length $c\text{²}$ that contains $N_c = \frac{c\text{²}}{\text{ª}}$ turns. In the reference frame K', associated with the photon, in each turn there is a current $I' = \frac{N_1 e_{pr}}{T'} = \frac{N_1 e_{pr} \text{µ}'}{2\text{®}}$. Here ² is the duration of the photon emission from the atom, N_1 denotes the number of particles carrying the praon's charge e_{pr} in one turn, and the product $N = N_1 N_c$ determines the total number of charges, involved in the magnetic field creation.

The mass $\bar{m}$ in (38) is a certain effective mass and is close to the praon mass m_{pr}; the difference between these masses is due to the fact that the photon is not a solid cylinder but a helical structure. Besides, the cross section of the photon in Figure 4 has the form of lobes, and the mass density in the lobes must be a function of the distance from the axis OZ. In the reference frame K' the angular momentum is written as in (38), and taking into account (35) and (38) we have:

$$L'_p = \frac{1}{2} N \gamma' \bar{m} R_0^2 \omega' = \frac{N \bar{m} R_0^2 \gamma'^2 \omega}{4\gamma} = \frac{\gamma'^2 \hbar}{2\gamma^2}. \tag{42}$$

The magnetic field inside a long solenoid depends only on the number of turns per unit length $n' = \frac{1}{\lambda'}$ and on the flowing current $I' = \frac{N_1 e_{pr} \omega'}{2\pi}$:

$$B'_z = \mu_0 n' I' = \frac{\mu_0 I'}{\lambda'} = \frac{\mu_0 N_1 e_{pr} \omega'}{2\pi \lambda'}.$$

Substituting here $N_1 = \frac{N}{N_c} = \frac{N\lambda}{c^2}$, using (35) and (41), and expressing N in terms of $\hbar$ from (42), we find:

$$B'_z = \frac{\mu_0 N \lambda e_{pr} \omega'}{2\pi \lambda' c^2} = \frac{\mu_0 N \lambda e_{pr} \gamma' \omega}{4\pi \lambda' c^2 \gamma} = \frac{\mu_0 N e_{pr} \gamma'^2 \omega}{8\pi c^2 \gamma^2} = \frac{\mu_0 e_{pr} \gamma'^2 \hbar}{4\pi c^2 \gamma^3 \bar{m} R_0^2} = B_z. \tag{43}$$

If we substitute here the data for the photon under consideration: $\gamma' \approx 1$, $\gamma = 1.9 \cdot 10^{11}$, $\tau = 9.8 \cdot 10^{-10}$ s, $R_0 = 4a_B$, $e_{pr} = 4.6 \cdot 10^{-57}$ C, and if instead of $\bar{m}$ we use the praon mass

$m_{pr} = 1 \cdot 10^{-84}$ kg, we obtain the estimate of the longitudinal magnetic field inside the photon: $B'_z = B_z = 5.4 \cdot 10^{-28}$ T.

The magnetic field in the reference frame K is associated with a certain effective current I in the turns of the solenoid, which models the photon:

$$B_z = \frac{\text{«}_0 I}{\text{a}}.$$

We introduce the effective current into consideration because the charged praons in K do not just revolve around the axis OZ, but also fly along this axis at the velocity V_z. Taking into account the above-mentioned and the ratios $N_c = \frac{c^2}{\text{a}}$ and (43), on the assumption $\overline{m} = m_{pr}$, we find a dipole magnetic moment of the photon of insignificant value in the reference frame K:

$$P_m = \text{®}\, R_0^2 N_c I = \frac{\text{®}\, R_0^2 N_c B_z \text{a}}{\text{«}_0} = \frac{\text{®}\, R_0^2 B_z c^2}{\text{«}_0} = \frac{e_{pr} \text{¥}'^2 \hbar}{4 \text{¥}^3 m_{pr}} = 1.8 \cdot 10^{-41}\ \text{A} \cdot \text{m}^2. \qquad (44)$$

If the negative praons move as is shown in Figure 4, and the photon propagates in the positive direction of the axis OZ, then the magnetic moment of the photon would be directed in the negative direction of the axis OZ and opposite to the photon velocity. If the photon propagates oppositely to the axis OZ, the direction of the magnetic moment and the velocity of the photon will coincide.

The ratio of the magnetic moment of the photon under consideration to the Bohr magneton is equal to $\frac{P_m}{\text{«}_B} = 1.9 \cdot 10^{-18}$. Note that in [20], based on the astrophysical data, there is a restriction of the magnetic dipole moment of the photon, which must not exceed $5\cdot 10^{-14}$ «$_B$. In the previous section we found that the Lorentz factor ¥ increases in proportion to the nuclear charge number Z in the hydrogen-like atom or in proportion to the square root of the photon energy: ¥ $\sim \sqrt{\frac{W}{i}}$. Then from (44) it follows that the low-energy photons have an increased magnetic moment. In addition, the magnetic moment of the photon must increase in transitions with large quantum numbers i, corresponding to the electron orbits, which are distant from the nucleus.

In [9] we studied the structure of various neutrinos and the ways of their formation, and it was shown that the muon and electron neutrinos contain the fluxes of the same particles (electron neutrinos of the praon level of matter) and differ in the energy spectrum and in the method of ordering (helicity) of the angular momenta of these particles as well as their fluxes in space. Due to this, electron and muon neutrinos can partially transform into each other. Neutrinos emerge in the weak interaction processes and differ from photons by their internal structure. Photons are most often generated during interaction of the praons’ fluxes of the vacuum field with the accelerated lepton matter; and neutrinos are more typical for the processes inside the hadrons matter.

Despite the different structures of the photon and neutrino, we assume that neutrinos of the atomic level of matter, like photons, consist of praons and have a magnetic moment. Therefore we will present the estimates of the dipole magnetic moment of neutrinos: not more than 10^{-10} «$_B$, according to [21]; not more than $3\cdot 10^{-12}$ «$_B$, according to [22]; not more than 10^{-14} «$_B$, according to [23]. As we can see, the dipole magnetic moment (44) for the photon in the hydrogen atom does not exceed the values, which is expected for the neutrino.

9. THE PHOTON MASS

In the special theory of relativity there is a well-known formula, connecting the relativistic energy W, momentum $\mathbf{p}$ and invariant mass m (the rest mass) of the particle:

$$W^2 = p^2c^2 + m^2c^4 . \tag{45}$$

In [24] the restriction was given for the photon's rest mass: $m < 1 \cdot 10^{-14}$ eV/s^2 in energy units, and in [25] it is assumed that $m < 1 \cdot 10^{-18}$ eV/s^2. As a rule, it is believed that the rest mass of the photon is zero, $m = 0$, and then the photon energy depends only on its momentum: $W = \hbar \mu = pc$. The latter ratio allows us to find the photon's momentum using the energy or angular frequency of the photon. In this case the photon must move at the speed of light c.

Let us consider the case of the photon mass in the substantial model described above. From (38) we can determine the relativistic energy of the particles inside the photon by multiplying the number of praons by the average rest mass of one particle $\bar{m}$, by the Lorentz factor and by the square of the speed of light:

$$E_{pr} = N ¥ \bar{m} c^2 = \frac{2\hbar c^2}{R_0^2 \mu} = \frac{2W c^2}{\mu^2 R_0^2} . \tag{46}$$

In (46) μ denotes the angular frequency of the photon, $W = \hbar \mu$ is the photon energy, and the product $\mu R_0 = \langle V \rangle$ in its meaning is the averaged speed of rotation of the electron in the atom during the photon emission. Consequently, the relativistic energy of praons is $\frac{2c^2}{\langle V \rangle^2}$ times greater than the photon energy. By the order of magnitude, the difference between the energies E_{pr} and W is about tens of thousands and more.

The invariant mass of the photon, understood as the invariant mass of the praons that make up the photon, in view of (46) is equal to:

$$m_{ph} = \frac{E_{pr}}{¥ c^2} = N\bar{m} = \frac{2\hbar}{¥ R_0^2 \mu} . \tag{47}$$

Substituting into (46) and (47) the data for the photon, emitted by the hydrogen atom during the electron's transition from the second to the first level in the Lyman series: $\mu = 1.54946 \cdot 10^{16}$ s^{-1}, $R_0 = 4a_B$, $¥ = 1.9 \cdot 10^{11}$, we obtain the following estimates: $E_{pr} = 2.7 \cdot 10^{-14}$ J or 170 keV, $m_{ph} = 1.6 \cdot 10^{-42}$ kg or $9 \cdot 10^{-7}$ eV/c^2 in energy units. It turns out that the rest mass of the photon's particles m_{ph} is not equal to zero, though it is quite low.

In (40) it was found that $¥ \sim \frac{Z}{i^2}$, while $R_0 \sim \frac{i^2}{Z}$ and $\mu \sim Z^2 \left(\frac{1}{j^2} - \frac{1}{i^2} \right)$. Therefore, $m_{ph} \sim \frac{i}{Z}$, that is the total rest mass of the particles of the emitted photon increases in the atomic transitions with large quantum numbers i and reaches the maximum for the hydrogen atom with the nuclear charge number $Z = 1$.

Instead of (45), for the photon we can write:

$$E_{pr}^2 = p_{pr}^2 c^2 + m_{ph}^2 c^4. \qquad (48)$$

Since the rest energy of the photon's particles $m_{ph} c^2$ is very low, in (48) the relativistic energy of the photon's particles E_{pr} is close to the product of the momentum by the speed of light: $p_{pr} c \approx ¥ m_{ph} V_z c \approx ¥ m_{ph} c^2 = E_{pr}$. This is due to the fact that the Lorentz factor ¥ of the particles inside the photon is very large.

From the stated above we can see why in (48) the rest mass of the photon's particles m_{ph} is not equal to zero, while in (45) the photon mass m is equated to zero. This follows from the difference between the energies E_{pr} and W – if the energy W is associated only with the rotation energy of the praons inside the photon and with the energy of their fields, then the energy E_{pr} also takes into account the energy of praons' motion at the velocity V_z, almost reaching the speed of light. This additional energy is not transferred to the praons from the electrons in the photon emission from the atom, but they had this energy at the time of interaction of the praons' fluxes with the electron. Not taking into account the initial energy of praons in the energy W leads to the loss of their rest mass and to zeroing of the mass m in (45) for the photon. In addition, the difference arises between the momentum of praons p_{pr} in (48) and the generally accepted photon momentum p in (45).

Despite the fact that the rest mass of the photon particles m_{ph}, calculated by us, significantly exceeds the estimates of the photon mass in [24] and in [25], the mass m_{ph} cannot be directly found in experiments. This is due to the fact that during interaction of the photon with the matter, the photon's angular momentum of the order of $\hbar$ is transferred to the matter, as well as the corresponding energy and momentum. However, the main part of the photon energy, involved in the relativistic motion of praons, is carried away with them at the moment of the photon decay and its scattering into separate praons.

We assume that the velocities V of the fluxes of praons in the vacuum field are of the order of the speed of light, $V \leq c$. At the same time, the photons are moving at the velocity V_z, and we should have $V_z \leq V$. Some difference between V_z and V is explained by the fact that the praons in the photon do not only move along the axis OZ, which is perpendicular to the plane of the electron disk at the moment of the photon emission, but they also rotate around this axis by some spirals. Rotation of the praons depends on the photon frequency and energy, which should influence the velocity of the photons V_z and lead to some initial velocity dispersion of the photons of different frequencies.

10. CONCLUSION

In Section 2, we show that the frequency of the photon, emitted from the atom, is equal to the rotation frequency of the electron cloud's center around the nucleus, averaged with respect to the time of the photon emission during quantum transition of the electron from a certain state to a state with lower energy.

In Section 3 we present the expressions for the electromagnetic field strength in the wave zone away from the charge, rotating around a certain center, which can be used to estimate the electromagnetic energy flux. From these, it follows that most of the energy is emitted from the charge in the rotation axis direction. In other directions the energy flux decreases quite rapidly in magnitude and has an oscillating character, without producing noticeable emission.

Taking as a basis the electromagnetic fields in the near zone and the wave zone from the hydrogen-like atom that undergoes quantum transition, we estimate the action of these fields on the charged particles (praons) of the vacuum field. The electron in the substantial model of the electron [9] is considered as a disk, and the above-mentioned fields cause rotation of the praon fluxes around an axis, which is perpendicular to the electron disk. Based on the pattern of the field in Section 4, in Section 5 we present the corresponding photon structure. The positively charged praons are concentrated near the photon's axis, and the negatively charged praons form the helical part of the photon. Based on this structure, with the help of the idea of strong gravitation at praon level we solve the problem of stability of the positively and negatively charged praons inside the photon, explaining the long-term stability of the photon by the huge value of the strong gravitational constant G_{pr}. Rotation of the negative praons inside the photon leads to the fact that photons can easily interact with electrons and other charged particles, exchanging the energy with each other.

The photon is emitted along the axis of the electron disk, but some part of the energy in the form of electromagnetic emission leaves the excited atom in other directions. This emission is in phase with the oscillations inside the photon. The latter can explain the results of the Young's interference experiment with low light intensity, when interference between single photons is observed. In this case, each photon passes through a particular slit and the coherent emission from the atom, associated with it, passes through another slit, which as a result gives the interference pattern.

In Sections 6-8, we estimate the values of the fields inside the photon, the Lorentz factor for the praons and the energy fluxes, we calculate the longitudinal magnetic field and the magnetic dipole moment of the photon. Here we use Lorentz transformations in order to turn to the reference frame, moving synchronously with the photon.

We finish development of the substantial model of the photon by considering the question of the invariant mass of the photon, which in the special theory of relativity is assumed to be equal to zero. In contrast, in the substantial model we calculate the rest mass of the praons that make up the photon, which obviously cannot be zero. Using this mass and the total momentum of the praons, we determine the relativistic energy of these praons, which tens of thousands times exceeds the energy of the photon in the classical theory. The difference between these energies is explained by the fact that the generally accepted photon energy does not include the relativistic energy of the praons, moving almost at the speed of light. As a result, in our model the photon is described by a standard relativistic formula, which relates its energy, momentum and the nonzero rest mass.

According to the ordinary interpretation, the photon is considered as an elementary particle, which is a quantum of electromagnetic emission, and its uniqueness is enhanced by the absence of the rest mass. In quantum electrodynamics, the photon is also a gauge boson, while the carriers of electromagnetic interaction are considered virtual photons. However, in [14] we have shown that the electromagnetic forces can occur under the action exerted on the charged bodies by multiple fluxes of praons that exist in the vacuum field. In this article we consider the processes that take place in quantum electron transitions in the atom, which allow forming photons from the fluxes of praons. Thus, the concept of praons allows us not only to understand the photon structure and to find its mass, but also to give a general explanation of the main electromagnetic phenomena.

If the photon has non-zero mass, then how could it change our understanding of the effect of light deflection by massive bodies under the action of gravitation? According to [15], gravitation is explained in Le Sage's model as the result of the action exerted on the bodies by the fluxes of gravitons in the vacuum field. As a whole the vacuum field consists of two components, the field of gravitons and the field of charged praons, generating gravitational and electromagnetic forces, respectively. The photon is an object composed of praons, tightly bound by strong gravitation and electromagnetic forces. The fluxes of praons near massive bodies deflect from their initial direction under the action of the graviton field. In this case the photon is not just a flux of praons, it carries additional energy and angular momentum, acquired at the time of emission. Moving at relativistic velocity, the photon must be influenced by the graviton field, just like other particles having the same velocity are influenced by this field. For example, in the covariant theory of gravitation [26], the full angle of deflection is given by the formula: $2¤ = \frac{4GM}{V_\infty^2 R_\infty}$, where M is the body mass, V_∞ and R_∞ denote the velocity and the impact parameter of the relativistic particle at infinity. If we assume for the photon $V_\infty = V_z \approx c$, we will arrive at the formula $2¤ \approx \frac{4GM}{c^2 R_\infty}$, which would be valid for the photon in the general theory of relativity as well. In this formula, there is no dependence on the mass of the relativistic particle or on the photon mass. Therefore, emerging of the photon's rest mass will change the full angle of deflection $2¤$ by a very small quantity, arising from the difference between the photon velocity and the speed of light.

The substantial model provides its solution of the wave-particle duality of the photon. As an estimate of the number of praons in the photon we used, emitted by the hydrogen atom, we will calculate the relation: $\frac{m_{ph}}{m_{pr}} = 1.6 \cdot 10^{42}$ praons. This entire set of praons is tightly bound by the electromagnetic forces and strong gravitation at the level of praons, ensuring the integrity and long-term stability of the photon as a particle. On the other hand, due to its origin, the photon represents a long and rotating in space periodic structure of small cross section. Due to this structure, the photon exhibits wave properties, in particular by means of its field strengths, periodically varying in space and time.

From the stated above it also follows that due to the small difference of the photon velocity V_z from the speed of light, the recorded photon velocity would not the same for observers in the reference frames, moving at different speeds. In particular, we assume the existence of the reference frame K', in which the longitudinal velocity of the photon as a whole is equal to zero and there is only its proper rotation.

It is convenient to assume that the speed of light is the limiting value for the motion of photons and particles. In transition to the lower levels of matter (to nucleons, praons, etc.) the Lorentz factor increases in the particles that make up the photons of the respective matter level, while their velocities must not exceed the speed of light. Thus the theory of relativity is applied in the theory of infinite nesting of particles. On the other hand, if the proton is accelerated by the electromagnetic forces, actually by the directed and concentrated fluxes of charged, relativistically moving praons, then the proton velocity cannot exceed the velocity of these praons. If any photon and the praons, forming it, are moving at a velocity less than the speed of light, then the proton velocity, accelerated by such praons, will not be able to reach the speed of light. The relativistic praons, that in the aggregate form the field of charged particle of the vacuum field, acquired their energy in the electromagnetic fields near the protons and other charged particles. Only the electromagnetic field is the basic source of relativistic charged particles at all levels of matter, and then it turns out that all these particles are moving more slowly than the speed of light.

According to the theory of infinite nesting of matter and calculations with the use of similarity coefficients, the invariant mass of a positively charged praon must be $m_{pr} = \frac{m_p}{\text{c}} = 1 \cdot 10^{-84}$ kg and the radius must be $r_{pr} = \frac{r_p}{P} = 6.2 \cdot 10^{-35}$ m with the proton radius equal to $r_p = 8.73 \cdot 10^{-16}$ m, according to [18]. Apparently, in modern experiments individual particles of such low masses and sizes cannot be detected directly. Actually, the search for preons, as the particles that make up quarks and leptons, and for partons, as the constituent particles of nucleons, in experiments on scattering of particles reached only the size of 10^{-18} m. This is much larger than the expected size of praons. As a result, partons were identified as quarks and gluons, and preons as a type of new particles were not detected and remained to be the subject of theoretical research [27].

In our opinion, the maximum possible photon energy W, as well as the invariant mass of its particles m_{ph}, depend significantly on the way of the photon formation. If in (39) we equate the doubled density $£_{em}$ of the electromagnetic energy inside the photon to the energy density of the charged particles of the vacuum field $£_{cq}$, and take from [14] the value $£_{cq} = 4 \cdot 10^{32}$ J/m^3, we can estimate the maximum amplitude of the electric field strength inside the photon:

$$E_0 = \sqrt{\frac{\varepsilon_{cq}}{\varepsilon_0}} = 6.7 \cdot 10^{21} \text{ V/m.} \tag{49}$$

In (49) it is assumed that the charged particles of the vacuum field (praons) are part of the photons at the time of their formation, and the energy density of the photons ε_{em} cannot exceed the energy density ε_{cq}. The latter follows from the fact that ε_{em} is associated with rotation of the praons inside the photon, where the rotation speed does not exceed the speed of light, and ε_{cq} is the averaged energy density of the praons in their motion at the velocity of the order of the speed of light. The electric field strength (49) can be compared only with the field strength at the surface of the proton, where $E_p = \frac{e}{4\pi\varepsilon_0 r_p^2} = 1.9 \cdot 10^{21}$ V/m. Therefore, formation of high-energy photons can be associated with the relativistic protons and interactions with them, as is the case with the cosmic rays.

In [15] we estimated the temperature of the graviton field, which is part of the vacuum field, for the case when gravitons are the particles similar to photons: $T = 5.6 \cdot 10^{12}$ K. Let us assume that the field of the charged particles of the vacuum field has the same temperature as the graviton field, and both fields are in temperature equilibrium. Assuming in a first approximation, that the Wien's displacement law holds true for the wavelength $\lambda_{\max}$, that the majority of photons have at the given temperature T, with regard to the Wien's displacement constant $b = 0.002898$ m$\cdot$K, we find:

$$\lambda_{\max} = \frac{b}{T}, \qquad W_{\max} = \frac{hc}{\lambda_{\max}} = \frac{hcT}{b} = 3.8 \cdot 10^{-10} \text{ J.}$$

In terms of energy units of particle physics the average photon energy equals $W_{\max} = 2.4$ GeV and belongs to the range of gamma-quanta. Assuming that in (37-38) the radius R_0 can be replaced by the proton radius r_p and the speed of light can be used as the limiting speed of praons' rotation in the photon: $\mu R_0 = \mu_{\max} r_p = c$, then for the maximum energy of such a photon we find: $W_{\max} = \hbar \mu_{\max} = \frac{\hbar c}{r_p} = 0.2$ GeV.

However, measurements show that the energy of photons can be much higher and can reach 80 TeV [28]. Apparently, the photons with such energies are formed not under condition of temperature equilibrium between the matter and electromagnetic field, but under strongly non-equilibrium conditions. This requires interaction of a relativistic particle with a great number of particles at the same time. The examples are the synchrotron emission of a charged particle in the magnetic field of a sufficiently large and magnetized object, and the inverse Compton effect.

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