Derivation of the Proton's Magnetic Moment beyond QED and QCD Theories

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Abstract. The first precise derivation of the proton's magnetic moment based on the Dynamic Model of Elementary Particles (DM), beyond quantum electro- and chromodynamics, is presented in this paper. Longitudinal and transversal exchange interactions and corresponding to them longitudinal and transversal exchange charges, originated from the DM, were taken into account at the derivation. The results presented, along with other works of the author, including the derivation of electron's and neutron's magnetic moments, confirm the advantage of the DM.

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1. Introduction

The current experimental value of the proton magnetic moment, according to the 2006 CODATA internationally recommended values, is

$$\mu_p = 1.410606662(37)\cdot 10^{-26}\ J\cdot T^{-1}. \tag{1.1}$$

This value is approximately in 1.46 times more than those one for the neutron, which is

$$\mu_n = -0.96623641(23)\cdot 10^{-26}\ J\cdot T^{-1}. \tag{1.2}$$

The reason of such a distinction between two observed quantities is not yet clearly understood by modern physics [1-18]. In our opinion, situation with this issue exists because contemporary physics, based on the Standard Model (SM), does not know till now the *true nature of charge* of elementary particles, which is responsible for their magnetic properties. Lacks of the SM are well-known, but all attempts of physicists to improve this model are unsuccessful. The matter is that the fundamental primordial problem of physics, which is the *problem on the mass and charge nature,* cannot be solved in principle by the traditional way based on formal logic.

A qualitatively new approach in physics based on dialectical logic, developed in the last decade, solved the problem of mass and charge nature. This was realized in the framework of the Dynamic Model of Elementary Particles (DM) [19], which is a part of the Dialectical Model of the Universe. According to the DM, the mass of elementary particles has the *associated* character and is the *measure of exchange* of matter-space-time, and the rest mass does not exist. The notion of *exchange* instead of interaction is one of the principal notions in the DM. The latter distinguishes the *longitudinal* exchange and the *transversal* exchange as two opposite sides of the process of interaction of particles with surrounding fields and particles themselves. The *longitudinal exchange* is characteristic for *spherical fields* of particles at rest and motion. The *transversal exchange* is characteristic for *cylindrical fields* of moving particles only.

The rate of mass exchange defines the *exchange charge*, its dimensionality is $g \cdot s^{-1}$. Two notions of exchange charge correspond to two types of exchange: the *longitudinal* ("*electric*") exchange charge and the *transversal* ("*magnetic*") exchange charge. The transversal charge is generated during the motion of particles. The central exchange is considered in detail in [19].

A neutron, regarded in the DM as a proton-electron system, unstable in a free state, is an electrically neutral microformation as a whole in which positive (longitudinal) exchange charge of the core of the neutron is compensated by the opposite, negative, transversal exchange charge of an electron being in a state of motion in the system. Accordingly, a moving neutron does not generate the transversal exchange charge because transversal exchange is not inherent in neutral particles. And, as in the case of the hydrogen atom, that is the proton-electron system as well, the constituent electron defines a negative magnetic moment of the neutron.

A single free proton has longitudinal exchange charge, equal in value to the minimal quantum of the rate of mass exchange, which is not compensated (as against of the neutron). Therefore, during motion it generates the transversal charge, which defines the transversal, magnetic field.

Thus both exchanges and corresponding to them exchange charges, longitudinal and transversal, define the proton's magnetic moment. The latter is convincingly shown in this paper. On the basis of the above concepts, the proton's magnetic moment is derived with the high precision in full agreement with the experimental data.

This paper is a natural continuation of the works devoted to the derivation of electron's and neutron's magnetic moments [20, 21] and the Lamb shift in the hydrogen atom [22] carried out by the author on the basis of the DM. Therefore we will not repeat here in detail all features of the DM, including the notion of central exchange, which are considered in the easily accessible reference works.

2. A general formulation for the derivation of the proton's magnetic moment

The spectrum of amplitude magnetic moments of nucleons (protons and neutrons) as dynamic (wave) microformations, in accordance with the DM, is described by the formula

$$\mu = \frac{\upsilon_0}{c} q \frac{A\hat{e}_l(z_{p,s})}{z_{p,s}}, \tag{2.1}$$

where

$$A = r_0\sqrt{\frac{2hR}{m_0 c}} \tag{2.2}$$

is the constant,

$$\hat{e}_l(kr) = \sqrt{\pi kr/2}\,(J_{l+1/2}(k_e r) \pm iY_{l+1/2}(k_e r)), \tag{2.3}$$

$$k_e = \omega_e / c = 1/ƛ_e, \tag{2.4}$$

$$z_{p,s} = k_e r. \tag{2.5}$$

Here υ_0 and r_0 are the Bohr speed and radius, respectively; c is the speed of light; q is the charge of *exchange* of the nucleon with environment, $g \cdot s^{-1}$ [19]; A is the constant; $J(kr)$ and $Y(kr)$ are Bessel functions; k_e is the wave number; ω_e is the oscillation frequency of the pulsating spherical shell of the proton equal to the fundamental "carrier" frequency of the subatomic and atomic levels; $z_{p,s}$ are roots of Bessel functions [23]. The subscript p in $z_{p,s}$ indicates the order of Bessel functions and s, the number of the root. The last defines the number of the radial shell. Zeros of Bessel functions define the radial shells with zero values of radial displacements (oscillations), *i.e.*, the shells of stationary states.

An *elementary quantum of the magnetic moment of a nucleon* in a node of the spherical field is equal to [24]

$$\mu = \frac{\upsilon_0}{c} q A_m, \tag{2.6}$$

where A_m is amplitude with which a nucleon as a whole oscillates in a node of the spherical wave field of exchange,

$$A_m = ƛ_e \sqrt{\frac{2Rh}{m_0 c}} = 2.73065189 \cdot 10^{-12}\ cm, \tag{2.7}$$

where

$$ƛ_e = c / \omega_e = 1.603886514 \cdot 10^{-8}\ cm \tag{2.8}$$

is the wave number, ω_e is the fundamental frequency of the subatomic level,

$$\omega_e = 1.869162534 \cdot 10^{18}\ s^{-1}. \tag{2.9}$$

The amplitude A_m is the characteristic amplitude of oscillations on the sphere of the wave radius ($z_{p,s} = kr = 1$).The Rydberg constant is

$$R = \frac{R_\infty}{1 + m_e / m_0} = 109677.5833\ cm^{-1}. \tag{2.10}$$

Other fundamental quantities used here are: the proton mass is $m_0 = 1.672621637(83) \cdot 10^{-24}\ g$, the Planck constant is $h = 6.62606896(33) \cdot 10^{-27}\ erg \cdot s$, and $c = 2.99792458 \cdot 10^{10}\ cm \cdot s^{-1}$.

The exchange charge q, being the measure of the *rate of exchange of matter-space-time*, or briefly the *power of mass exchange*, is defined as

$$q = \frac{dm}{dt} = S\upsilon\varepsilon, \tag{2.11}$$

where S is the area of a closed wave surface separating the inner and outer space of an elementary particle, υ is the oscillatory speed of exchange at the separating surface, ε is the absolute-relative density. The exchange charge q and the Coulomb charge q_C (presented in the CGSE units) are related as

$$q = q_C \sqrt{4\pi\varepsilon_0}\,, \tag{2.12}$$

where $\varepsilon_0 = 1\, g \cdot cm^{-3}$ is the absolute unit density.

The value (2.6) is the main constituent of the magnetic moment of nucleons (both a neutron and a proton). But in this formula, in the case of the free proton, the total exchange charge q is equal to the minimal quantum of the rate of (longitudinal) mass exchange and an additional transversal exchange charge of the positive sign.

At the same time a nucleon, as a dynamic, pulsing microobject in accordance with the DM, oscillates with respect to its own center of mass with the amplitude (2.2). These perturbations in motion of a nucleon defined by the amplitude superimpose on the circular motion of the nucleon. Hence, the second in value term to the nucleon's magnetic moment (2.6) is defined (in this case $z_{p,s} = z_{0,s}$) by the following formula

$$\delta\mu_1 = \frac{q\upsilon_0}{c}\frac{r_0}{z_{0,s}}\sqrt{\frac{2Rh}{m_0 c}}\,. \tag{2.13}$$

The charge q in (2.13), for the case of a neutron, regarded as a proton-electron system, is defined by only electron's exchange charge, so that $q = -e$, which is mutually balanced with the opposite in sign central longitudinal proton's exchange charge.

For the free proton, whose exchange with the surrounding field is not compensated with the opposite in sign exchange charge of the electron because of the absence of the latter, the total exchange charge of the proton q is defined by the *longitudinal non-compensated positive exchange charge* of the proton, $+e$, and supplementary *associated transversal exchange charge*, Δe_p, generated during its motion:

$$q = +e + \Delta e_p\,. \tag{2.14}$$

where

$$+e = 1.702691582 \cdot 10^{-9}\ g \cdot s^{-1}\,. \tag{2.15}$$

Thus, according to (2.1), the circular wave motion of the proton generates the magnetic (transversal) moment μ (2.6). Small deviations of the motion generate an additional magnetic moment (2.13), which must be taken into account for the total magnetic moment of the proton.

The theoretical value of the total magnetic moment of the proton $\mu_p(th)$ is defined thus by the following equation

$$\mu_p(th) = \frac{(e + \Delta e_p)\upsilon_0}{c}\left(\lambdabar_e + \frac{r_0}{z_{0,s}}\right)\sqrt{\frac{2Rh}{m_0 c}}\,. \tag{2.16}$$

In this formula, the unknown magnitude is the *supplementary associated charge* of the proton, Δe_p, generated during the non-compensated transversal exchange with environment of the moving proton. The roots of Bessel functions $z_{0,s}$, which define wave shells of the proton, can be easy chosen from a series of roots obtained from solutions of the wave equation [25]. Other values entered in (2.16) were presented above.

The transversal positive charge Δe_p is the unknown earlier, but very important physical quantity [24]. We will elucidate the notion of transversal exchange directly connected with the longitudinal exchange, being both the fundamental concepts of the DM. What does the transversal exchange mean, and hence, what do the transversal associated mass and the transversal associated charge related to the exchange mean? Let us proceed now to consider this question in detail.

3. The principal parameters of the wave physical space

According to the DM, the spaces of all levels of the Universe are mutually overlapped, embedding in each other. With this below laying spaces are the basis spaces for upper laying levels. The mass of microobjects of a level is regarded as a particular physical spherical point (like vortices or compressions, *etc*.) pulsing in space.

In view of this we regard the *mass* of physical space m as the *amount of the physical space* of the *embeddedness* ε defined by the equality

$$m = \varepsilon V = \varepsilon_r \varepsilon_0 V \,, \tag{3.1}$$

where V is the volume of the space. The embeddedness $\varepsilon = \varepsilon_r \varepsilon_0$ is, in other words, the density of the space, where ε_r is the relative density and $\varepsilon_0 = 1\ g \cdot cm^{-3}$ is the absolute unit density of the space.

If we reduce an amount of space m to the unit embeddedness, we can write (3.1) as

$$m = \varepsilon_r (\varepsilon_0 V) = \varepsilon_r V_0 \,, \tag{3.2}$$

where $V_0 = m$, because in the above mentioned meaning

$$g = cm^3 \,. \tag{3.3}$$

For the more accurate description of the wave physical space, we operate with the *kinematic vector-speed E* at the level of the basis wave space. To stress its directed character, one can use the symbol ***E***. The reference dimensionality of the vector-speed E is $cm \cdot s^{-1}$.

The dynamic vector, conjugate to the kinematic E-vector, is defined as

$$D = \varepsilon E = \varepsilon_r \varepsilon_0 E \,. \tag{3.4}$$

We see that the D-vector is a vector of the *density of momentum of physical space* with the embeddedness ε; its dimensionality is $(g \cdot cm / s) / cm^3$.

The vectors D and E are used for the description of *longitudinal* wave field. The analogous pair of the vectors, H and B, presents the *transversal* wave field:

$$H = \varepsilon B = \varepsilon_r \varepsilon_0 B \,. \tag{3.5}$$

The vectors D and E describe the *spherical* ("electric") wave field of the basis space; while H and B describe the *cylindrical* ("magnetic") wave field of the same basis space.

Along with the "right" embeddedness $\varepsilon = \varepsilon_r \varepsilon_0$, we operate also with the "inverse" embeddedness:

$$\mu_0 = 1/\varepsilon_0 \quad \text{and} \quad \mu_r = 1/\varepsilon_r . \tag{3.6}$$

Then, the equalities (3.4) and (3.5) take the form

$$E = \mu_r \mu_0 D, \qquad B = \mu_r \mu_0 H . \tag{3.7}$$

We postulate the validity of the equality $\varepsilon_r = 1$ for the basis space. This is quite natural, because, at this level, the embeddedness, in essence, relates to the space itself, *i.e.*, the *self-embeddedness* of the space takes place.

4. Longitudinal-transversal and potential-kinetic structure of wave fields

In wave field-spaces, the *central field-space* of exchange is inseparable from its *negation*, which is represented by the *transversal field-space* of exchange [24]. The central (longitudinal) field of exchange is described by two vectors, E and D, the transversal field is described by the analogous vectors, B and H. Thus, the B vector is the *speed-strength vector* and the H vector is a *vector of the density of momentum* of the transversal exchange.

Both fields-spaces (central and transversal) form the unit contradictory *longitudinal-transversal field-space* with the following vectors:

$$\hat{A} = E + iB \qquad \text{and} \qquad \hat{C} = D + iH . \tag{4.1}$$

In a general case, each vector of exchange (*E, D, B*, and *H*) has the contradictory *potential-kinetic* character (that is designated by the symbol ^) [26, 27]. Therefore, more correctly, (4.1) must be presented in the following form:

$$\hat{A} = \hat{E} + i\hat{B} \qquad \text{and} \qquad \hat{C} = \hat{D} + i\hat{H} , \tag{4.2}$$

where i is the *unit of negation* of the central field by the transversal field. Thus, the letter i indicates the transversal character of the field of $\hat{B}$ and $\hat{H}$ vectors as against the central field of E and D vectors. Simultaneously, the letter i indicates the *potential* character of the corresponding vectors, as the negation of the kinetic ones, because

$$\hat{E} = E_k + iE_p , \quad \hat{B} = B_k + iB_p , \quad \text{and} \quad \hat{D} = \varepsilon_0 \varepsilon_r \hat{E} , \quad \hat{H} = \varepsilon_0 \varepsilon_r \hat{B} . \tag{4.3}$$

Obviously,

$$A_k = E_k + iB_k , \qquad C_k = D_k + iH_k \tag{4.4}$$

and

$$A_p = E_p + iB_p , \qquad C_p = D_p + iH_p . \tag{4.5}$$

Each above vector of exchange belongs to the generalized vector of exchange

$$\hat{\Psi} = U + iV\,, \tag{4.6}$$

where $\hat{\Psi} \in (\hat{E}, \hat{B}, \hat{D}, \hat{H}, \hat{A}, \hat{C})$. This vector satisfies the wave equation

$$\Delta\hat{\Psi} - \frac{\partial^2 \hat{\Psi}}{\partial \tau^2} = 0\,, \tag{4.7}$$

which falls into the three scalar equations

$$\Delta\hat{\Psi}_x - \frac{\partial^2 \hat{\Psi}_x}{\partial \tau^2} = 0\,, \qquad \Delta\hat{\Psi}_y - \frac{\partial^2 \hat{\Psi}_y}{\partial \tau^2} = 0\,, \qquad \Delta\hat{\Psi}_z - \frac{\partial^2 \hat{\Psi}_z}{\partial \tau^2} = 0\,. \tag{4.8}$$

The field-space of the vectors of exchange repeats the structure of fields of matter-space-time, which have the longitudinal-transversal character. The longitudinal-transversal field of exchange $\hat{A} = \hat{E} + i\hat{B}$ is an image of the *longitudinal-transversal structure of the World*. At the subatomic level, it is called the *electromagnetic* field, in which the field of the *transversal* exchange (or more correctly the transversal subfield of the longitudinal-transversal field) is termed the "*magnetic field*" and the longitudinal exchange – the "*electric field*". The *binary field-spaces* are the basis of space of the Universe.

Strictly speaking, the electromagnetic field must be called by only one name: the "electric" (or "magnetic") longitudinal-transversal field with the *longitudinal-transversal charges*. This is a very important question of logical semantics of the field, which inclines to the definite concepts [24].

The binary fields-spaces are elementary links in a chain of mutually negating longitudinal-transversal spaces-fields, which form the multidimensional spatial structure of matter-space-time of the Universe.

5. The general solution of the cylindrical space

In a case of the *spherical field-space* of exchange, the structure of every component of the generalized vector of exchange takes the form

$$\hat{\Psi}_k = c_k \hat{R}_l(\rho)\Theta_{l,m}(\theta)\hat{\Phi}_m(\varphi)\,, \tag{5.1}$$

where $k \in (x, y, z)$. The same structure has the vector $\hat{\Psi}$

$$\hat{\Psi} = c_\Psi \hat{R}_l(\rho)\Theta_{l,m}(\theta)\hat{\Phi}_m(\varphi)\,. \tag{5.2}$$

The fields of *transversal exchange* are, mainly, the fields of *cylindrical* structure. The presence of a field of the cylindrical structure points to the motion of particles in the field of matter-space-time.

The transition from the rectangular one to the cylindrical reference space is defined by the equalities:

$$x = r\cos\varphi , \qquad y = r\sin\varphi , \qquad z = z . \tag{5.3}$$

The cylindrical space is the product of the radial, axial, azimuth, and time wave subspaces:

$$\hat{\Psi} = C_{\Psi}\hat{R}(k_r r)\hat{Z}(k_z z)\hat{\Phi}(\varphi)\hat{T}(\tau) , \tag{5.4}$$

where C_{ψ} is the scale factor, and $\tau = \omega t$.

A wave equation for the *cylindrical space* (in cylindrical coordinates) has the form:

$$\frac{\partial^2\hat{\Psi}}{\partial(k_z z)^2} + \frac{\partial^2\hat{\Psi}}{\partial(k_r r)^2} + \frac{1}{r}\frac{\partial^2\hat{\Psi}}{\partial k_r r} + \frac{1}{r^2}\frac{\partial^2\hat{\Psi}}{\partial\varphi^2} - k^2\frac{\partial^2\hat{\Psi}}{\partial\tau^2} = 0 , \tag{5.5}$$

where $k^2 = k_r^2 + k_z^2$. It falls into the time equation,

$$\frac{d^2\hat{T}}{d\tau^2} + \hat{T} = 0 , \tag{5.6}$$

and the three spatial equations:

$$\frac{d^2\hat{Z}}{d(k_z z)^2} + \hat{Z} = 0 ; \qquad \frac{d^2\hat{\Phi}}{d\varphi^2} + m^2\hat{\Phi} = 0 ; \tag{5.7}$$

$$\frac{d^2\hat{R}}{d(k_r r)^2} + \frac{1}{k_r r}\frac{d\hat{R}}{d(k_r r)} + \left(1 - \frac{m^2}{(k_r r)^2}\right)\hat{R} = 0 . \tag{5.8}$$

The product of solutions of these equations determines a general solution for the cylindrical space:

$$\hat{\Psi}_m = C_{\Psi}\hat{R}_m(k_r r)e^{-ik_z z}e^{-im(\varphi+\varphi_0)}e^{i\omega t} , \tag{5.9}$$

at that

$$\hat{R}_m(k_r r) = \sqrt{\pi/2}\hat{H}_m^{\pm}(k_r r) , \tag{5.10}$$

where $\hat{H}_m^{\pm}(k_r r)$ is Bessel's function of the third kind, or Hankel's function, and m is the order of the function; φ_0 is the initial phase of the azimutal wave. Hankel's function is equal to the sum (difference) of Bessel's functions of the first and second kinds, $J_m(k_r r)$ and $iN_m(k_r r)$:

$$\hat{H}_m^{\pm}(k_r r) = J_m^{\pm}(k_r r) \pm iN_m^{\pm}(k_r r) . \tag{5.11}$$

Bessel's function of the second kind is also called Neumann's function. We will call all above-mentioned functions simply Bessel's functions.

In the cylindrical field, the order of the radial function m defines the number of waves, which are placed on the definite orbit. In a simplest case, only half-wave can be placed on the orbit. So that such an orbit will be described by the function of the $m = 1/2$ order. Therefore, as a solution, we choose the function

$$\Psi_{1/2} = A\sqrt{\frac{\pi}{2}}(J_{1/2}(\rho) + iN_{1/2}(\rho))e^{-i(1/2\varphi+\varphi_0)}e^{-ik_z z}e^{i\omega t} \tag{5.12}$$

or

$$\Psi^+_{1/2} = Ai\frac{e^{i(\omega t-kr)}}{\sqrt{kr}}e^{-i(1/2\varphi+\varphi_0)}e^{-ik_z z}, \tag{5.13}$$

where the initial phase of the azimuth component of the radial divergent wave φ_0 is defined on the basis of the boundary conditions. Naturally, the "radial divergent wave" is not the full name of the wave, because it represents the wave structure of radial, azimuth, and axial waves-spaces. The axial wave, represented by the function (5.13), propagates along Z-axis in the positive direction. The convergent radial wave $\Psi^-_{1/2}$ corresponds to the divergent one,

$$\Psi^-_{1/2} = Ai\frac{e^{i(\omega t+kr)}}{\sqrt{kr}}e^{-i(1/2\varphi+\varphi_0)}e^{-ik_z z} \quad . \tag{5.14}$$

Both waves form *the dynamic stationary wave field in the radial direction*, expressed mathematically by the standing radial wave:

$$\Psi_{1/2} = \Psi^+_{1/2} + \Psi^-_{1/2} = ia\frac{\cos kr \cdot e^{i\omega t}}{\sqrt{kr}}e^{-i(1/2\varphi+\varphi_0)}e^{-ik_z z}. \tag{5.15}$$

Simultaneously, the $\Psi_{1/2}$-wave is the travelling wave in the azimuth and axial directions, positive with respect to the Z-axis:

$$\left(\Psi_{1/2}\right)^+ = ia\frac{\cos kr}{\sqrt{kr}}e^{-i(1/2\varphi+\varphi_0)}e^{i(\omega t-k_z z)}. \tag{5.16}$$

The corresponding wave, travelling in the negative direction, is

$$\left(\Psi_{1/2}\right)^- = ia\frac{\cos kr}{\sqrt{kr}}e^{i(1/2\varphi+\varphi_0)}e^{i(\omega t+k_z z)}. \tag{5.17}$$

Both waves form the standing wave in the radial and axial directions:

$$\Psi_{1/2} = ia\frac{\cos kr}{\sqrt{kr}}e^{i(1/2\varphi+\varphi_0)}\cos k_z z \cdot e^{i\omega t}. \tag{5.18}$$

However, in the azimuth direction, it is the travelling wave along the electron orbit. If we are not interested in the description of the axial wave, we can omit the axial component and to consider only the radial-azimuth subspace:

$$\Psi_{\frac{1}{2}} = ia\frac{\cos kr}{\sqrt{kr}}e^{i(\frac{1}{2}\varphi+\varphi_0)}\cdot e^{i\omega t}. \qquad (5.19)$$

As far as the distance r from the axial line increases, Bessel's function (5.11) is approximately described by the following formula

$$\hat{H}_m^{\pm}(k_r r) \approx \frac{e^{i\left(\frac{m\pi}{2}+\frac{\pi}{4}\right)}}{\sqrt{k_r r}}e^{\pm ik_r r}. \qquad (5.20)$$

In this case, the radial multiplicative component of the cylindrical space (5.10) takes the form

$$\hat{R}(\rho) \approx \hat{A}e^{\pm i\rho}/\sqrt{\rho}, \qquad (5.21)$$

where $\hat{A} = Ae^{i\left(\frac{m\pi}{2}+\frac{\pi}{4}\right)}$, and $\rho = k_r r = r/\lambda\!\!\!^{-}_r$ is an argument of the cylindrical function (expressed through the wave radii), defining the expansion of space in the radial direction.

The argument of the radial function cannot have a zero value. Its magnitude is restricted by some minimal radius of the axial line (or a tube of current), which represents the physical wave trajectory of motion of a particle in a cylindrical wave process.

Under the constant flow of energy through the cylindrical surface, the expression (5.21) is a strict one.

The definite cylindrical wave surface corresponds to every value of the argument. The extremes and nulls of potential and kinetic components of the radial function define the cylindrical surfaces of the potential and kinetic extremes and nulls. The potential-kinetic cylindrical shells are between these surfaces.

6. Associated mass and exchange charge of transversal exchange

As follows from (5.13) and (5.21), the density of oscillatory-wave energy (or pressure) in the cylindrical field-trajectory, at the constant mean power of energy flow in a radial direction, has the form [24]

$$\hat{p} = \frac{p_m}{\sqrt{k_r r}}\exp i(\omega t - k_r r). \qquad (6.1)$$

Let the speed of transversal exchange is defined (like at longitudinal exchange) as

$$\hat{\upsilon} = \upsilon(k_r r)\exp i\omega t, \qquad (6.2)$$

where $k_r = k = \omega/c$ is the wave number corresponding to the fundamental frequency of the field of exchange ω.

Like for the spherical field-space [19], the following relation is valid for the cylindrical field-space:

$$\hat{\upsilon} = -\frac{k_r}{\varepsilon_0 \varepsilon_r i\omega} \frac{\partial \hat{p}}{\partial (k_r r)} . \tag{6.3}$$

On the basis of the above equalities, we get that the density of oscillatory-wave energy at the wave characteristic surface of the radius a is defined by the following equality

$$\hat{p} = \frac{2a\varepsilon_0\varepsilon_r}{1+4(k_r a)^2}(1-2k_r ai)i\omega\hat{\upsilon} . \tag{6.4}$$

Hence, the power of *field exchange* at a section of cylindrical surface of the length l, $S = 2\pi al$, related to the cylindrical field around a trajectory of the moving proton, in our case (with allowance for $d\hat{\upsilon}/dt = i\omega\hat{\upsilon}$) will be:

$$\hat{p}S = \frac{4\pi a^2 l\varepsilon_0\varepsilon_r}{1+4(k_r a)^2}(1-2k_r ai)\frac{d\hat{\upsilon}}{dt} , \tag{6.5}$$

or

$$\hat{p}S = \hat{m}\frac{d\hat{\upsilon}}{dt} , \tag{6.5a}$$

where

$$\hat{m} = \frac{4\pi a^2 l\varepsilon_0\varepsilon_r}{1+4(k_r a)^2} - ik_r \frac{8\pi a^3 l\varepsilon_0\varepsilon_r}{1+4(k_r a)^2} \tag{6.6}$$

is the *associated field mass* at transversal exchange.

An equation of the transversal exchange in the radial direction has the form

$$m_0 \frac{d\hat{\upsilon}}{dt} = \hat{F} - \hat{p}S , \tag{6.7}$$

where m_0 is the *rest mass* of the particle; $\hat{F}$ expresses some additional exchange – the power of exchange with an object in the ambient space.

Replacing $\hat{p}S$ by the equality (6.5), we arrive at the equation of exchange, *i.e.*, in essence, at the common equation of motion accepted in physics from Newton's times in the form

$$\left(m_0 + \frac{4\pi a^2 l\varepsilon_0\varepsilon_r}{1+4(k_r a)^2} \right)\frac{d\hat{\upsilon}}{dt} + R\hat{\upsilon} = \hat{F} . \tag{6.8}$$

In this equation,

$$R = 2k_r a\omega \frac{4\pi a^2 l\varepsilon_0\varepsilon_r}{1+4(k_r a)^2} \tag{6.9}$$

is the *coefficient of wave resistance*, or the *dispersion* of rest-motion at transversal exchange.

The equation of powers of exchange (6.8) is presented thus in a classical form of Newton's second law, describing the motion in the field-space with the resistance R. At such a description, the expression in brackets represents the effective mass m of the particle:

$$m = m_0 + \frac{4\pi a^2 l \varepsilon_0 \varepsilon_r}{1 + 4(k_r a)^2} . \qquad (6.10)$$

Eq. (6.5a) describes exchange of motion. However, we are interested in the mass exchange, which is defined by exchange charges (2.11). In this case, the field component of mass exchange (6.5a) has to be presented in the following form:

$$\hat{p}S = \frac{d\hat{m}}{dt}\hat{\upsilon} \qquad \text{or} \qquad \hat{p}S = \hat{Q}\hat{\upsilon} , \qquad (6.11)$$

where $\hat{Q}$ is the active-reactive charge of exchange. Then, Eq. (6.8) takes the form

$$m_0 \frac{d\hat{\upsilon}}{dt} + \frac{4\pi a l \upsilon \varepsilon_0 \varepsilon_r}{1 + 4(k_r a)^2} i\hat{\upsilon} + R\hat{\upsilon} = \hat{F} , \qquad (6.12)$$

where $\upsilon = \omega a$ is the speed at the cylindrical surface. The tangential field of exchange, which is negation of the longitudinal field of exchange E (see Sect. 3 and Sect. 4), is described by the *speed-strength vector B* (3.7), which is equal therefore to

$$\hat{B} = i\hat{\upsilon} , \qquad (6.13)$$

where i is the unit ("indicator") of negation. Thus, we have

$$m_0 \frac{d\hat{\upsilon}}{dt} + \frac{4\pi a l \upsilon \varepsilon_0 \varepsilon_r}{1 + 4(k_r a)^2} \hat{B} + R\hat{\upsilon} = \hat{F} \qquad (6.14)$$

or

$$m_0 \frac{d\hat{\upsilon}}{dt} + q_\tau \hat{B} + R\hat{\upsilon} = \hat{F} . \qquad (6.15)$$

It should recall again that elementary particles of the DM are pulsing microobjects, so that their masses have *associated* character. Accordingly, the notion of the rest mass is not appropriate for such microobjects of principle Thus, we accept that in the transversal field of exchange, as in the spherical one, the rest mass of a particle m_0 is equal to zero.

Thus, we arrive at the following formula for the *associated transversal mass m_τ* and the *associated transversal charge q_τ* (at $\varepsilon_r = 1$):

$$m_\tau = \frac{4\pi a^2 l \varepsilon_0}{1 + 4(k_r a)^2} , \qquad (6.16)$$

$$q_\tau = \omega m_\tau = \frac{4\pi a l \upsilon \varepsilon_0}{1 + 4(k_r a)^2} . \qquad (6.17)$$

We will use now these formulas for the final derivation of the magnetic moment of a proton.

7. Magnetic moment of the proton

Motion of a proton has the wave character and represents a cylindrical ray-wave. Therefore, we must take into account the supplementary associated charge and mass generated at the transversal exchange in the cylindrical field. The supplementary associated mass of the ray element *l* is defined by the formula (6.16).

An element *l* of the ray can be defined by the following way. According to the approach developed in [24], we have to recognize that the *elementary quantum of the rate of mass exchange e* exists in the four states:

$$+e, \quad -e, \quad +ie, \quad -ie \tag{7.1}$$

The first two quanta have relation to the longitudinal ("electric") exchange, the rest two – to the transversal ("magnetic") exchange. An elementary transversal magnetic charge-flux at the level of the Bohr radius r_0 is

$$ei = \upsilon i \varepsilon_0 S = 2\pi r_0 l i \upsilon \varepsilon_0 , \tag{7.2}$$

where $\varepsilon_0 = 1\, g \cdot cm^{-3}$ is the absolute unit density, $e = 1.702691582 \cdot 10^{-9}\ g \cdot s^{-1}$ is the charge of exchange of the proton with environment equal in magnitude to the electron exchange charge, and $r_0 = 0.52917720859 \cdot 10^{-8}\ cm$ is the Bohr radius. Hence, the element *l* of the ray-wave is defined from the equality (7.2) as

$$l = \frac{e}{2\pi r_0 \upsilon \varepsilon_0} . \tag{7.3}$$

Under the condition $\upsilon = c$, the value of *l* is minimal and equal to:

$$l = \frac{e}{2\pi r_0 c \varepsilon_0} = 1.708182574 \cdot 10^{-12}\ cm . \tag{7.4}$$

Hence, the supplementary associated transversal mass of the proton, Δm_p, defined from (6.16), is

$$\Delta m_p = \frac{4\pi r_0^2 l \varepsilon_0}{1 + 4k_e^2 r_0^2} = 4.187602162 \cdot 10^{-28} g , \tag{7.5}$$

The exchange charge in the DM [19, 24], $q = dm/dt$ (2.11), is regarded as the rate of mass exchange; its amplitude value is equal to the product of the associated mass by the fundamental frequency of exchange at the subatomic level ω_e,

$$q = m\omega_e . \tag{7.6}$$

Hence, the supplementary associated charge Δe_p, corresponding to the mass (7.5), is equal to

$$\Delta e_p = \Delta m_p \omega_e = 7.827309069 \cdot 10^{-10}\ g \cdot s^{-1} . \tag{7.7}$$

Thus, the total charge of exchange of the proton wave shell with environment is

$$q = e + \Delta e_p = 2.485422489 \cdot 10^{-9}\ g \cdot s^{-1}. \tag{7.8}$$

Let us turn now to the formula (2.16) and choose the root of Bessel functions $z_{0,s}$ entered in the second term of this expression. Similar as in the case of the derivation of the neutron's magnetic moment, we select the radial solution near the twelfth wave shell. Owing to the more uncertainty, we take the average value of the two nearest roots $z_{0,s}$, namely $a'_{0,11} = 32.95638904$, equal to an extremum of the eleventh potential spherical shell, and $y_{0,12} = 35.34645231$, which is equal to the zero of the twelfth kinetic shell.

Under all above conditions, the formula (2.16) for the proton's magnetic moment takes the form

$$\mu_p(th) = \frac{(e + \Delta e_p)\upsilon_0}{c}\left(\lambda\!\!\!^{-}{}_e + r_0 \frac{(a'_{0,11} + y_{0,12})}{2(a'_{0,11} y_{0,12})}\right)\sqrt{\frac{2Rh}{m_0 c}}, \tag{7.9}$$

where $\upsilon_0 = \alpha c = 2.187691254 \cdot 10^8\ cm \cdot s^{-1}$ (α is the fine-structure constant [28]).

The substitution of all numerical values for quantities entered in (7.9) yields the following theoretical values for the total magnetic moment of the proton and its two constituents:

$$\begin{aligned}\mu_p(th) &= (4.952571882 + 0.04790508144) \cdot 10^{-23}\ g \cdot cm \cdot s^{-1} = \\ &= 5.000476963 \cdot 10^{-23}\ g \cdot cm \cdot s^{-1}\end{aligned} \tag{7.10}$$

In the SI units, since $1T = 10^4 / \sqrt{4\pi}\ cm \cdot s^{-1}$, Equality (7.10) is rewritten as

$$\begin{aligned}\mu_p(th) &= (1.397094734 + 0.0135137738) \cdot 10^{-26}\ J \cdot T^{-1} = \\ &= 1.410608508 \cdot 10^{-26}\ J \cdot T^{-1}\end{aligned} \tag{7.11}$$

Thus, we have obtained the theoretical value μ_p, which practically coincides with the current "2006 CODATA recommended value" (1.1) accepted for the magnetic moment of the proton. The absolute coincidence of the obtained theoretical value (7.11) with the averaged experimental (recommended) value (1.1) is easily achieved if one introduces a small empirical coefficient $1/\beta$ for the second term. Such an adjustment is justified in the framework of the approach accepted here, because it corrects indeterminacy in the weight contribution each of two selected shells (roots of Bessel functions). The coefficient $1/\beta$ takes into account this circumstance.

Thus finally, the formula for the magnetic moment of the proton (7.9) takes the form

$$\mu_p(th) = \frac{(e + \Delta e_p)\upsilon_0}{c}\left(\lambda\!\!\!^{-}{}_e + r_0 \frac{1}{\beta}\frac{(a'_{0,11} + y_{0,12})}{2(a'_{0,11} y_{0,12})}\right)\sqrt{\frac{2Rh}{m_0 c}} \tag{7.12}$$

At $\beta = 1.000136546$, we arrive at

$$\mu_p(th) = (1.397094734 + 0.013511928) \cdot 10^{-26}\ J \cdot T^{-1} = \\ = 1.410606662 \cdot 10^{-26}\ J \cdot T^{-1}, \qquad (7.13)$$

i.e., at the complete coincidence of the experimental value of the magnetic moment of the proton (1.1) with theoretical (7.13).

8. Conclusion

Thus for the first time a precise derivation of the proton's magnetic moment is realized in physics beyond DED and QCD theories. This result has been achieved due to taking into account the wave behaviour of the proton in the framework of the Dynamic Model of Elementary Particles.

Along with the previous derivation of electron's and neutron's magnetic moments [20, 21], and the Lamb "shifts" in the hydrogen atom [22], this work is the next stringent test for the validity of the concepts on the associated nature of mass of elementary particles and the exchange nature of charges regarded as the rate of mass exchange of the dimensionality $g \cdot s^{-1}$.

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