A Way to Revised Quantum Electrodynamics

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In conventional theoretical physics and its Standard Model the guiding principle is that the equations are symmetrical. This limitation leads to a number of difficulties, because it does not permit masses for leptons and quarks, the electron tends to "explode" under the action of its self-charge, a corresponding photon model has no spin, and such a model cannot account for the "needle radiation" proposed by Einstein and observed in the photoelectric effect and in two-slit experiments. This paper summarizes a revised Lorentz and gauge invariant quantum electrodynamic theory based on a nonzero electric field divergence in the vacuum and characterized by linear intrinsic broken symmetry. It thus provides an alternative to the Higgs concept of nonlinear spontaneous broken symmetry, for solving the difficulties of the Standard Model. New results are obtained, such as nonzero and finite lepton rest masses, a point-charge-like behavior of the electron due to a revised renormalization procedure, a magnetic volume force which counteracts the electrostatic eigen-force of the electron, a nonzero spin of the photon and of light beams, needle radiation, and an improved understanding of the photoelectric effect, two-slit experiments, electron-positron pair formation, and cork-screw-shaped light beams.

1 Introduction

Conventional electromagnetic theory based on Maxwell's equations and quantum mechanics has been successful in its applications to numerous problems in physics, and has sometimes manifested itself in an extremely good agreement with experiments. Nevertheless there exist areas within which these joint theories do not provide fully adequate descriptions of physical reality. As already stated by Feynman [1], there are unsolved problems leading to difficulties with Maxwell's equations that are not removed by and not directly associated with quantum mechanics. It has thus to be remembered that these equations have served as a guideline and basis for the development of quantum electrodynamics (QED) in the vacuum state. Therefore QED also becomes subject to the typical shortcomings of electromagnetics in its conventional form.

A way to revised quantum electrodynamics is described in this paper, having a background in the concept of a vacuum that is not merely an empty space. There is thus a nonzero level of the vacuum ground state, the zero point energy, which derives from the quantum mechanical energy states of the harmonic oscillator. Part of the associated quantum fluctuations are also carrying electric charge. The observed electron-positron pair formation from an energetic photon presents a further indication that electric charges can be created out of an electrically neutral vacuum state. In this way the present approach becomes based on the hypothesis of a nonzero electric charge density and an associated electric field divergence in the vacuum state. This nonzero divergence should not become less conceivable than the nonzero curl of the magnetic field related to Maxwell's displacement current.

The present treatise starts in Section 2 with a discussion on quantization of the field equations. This is followed in Section 3 by a description of the difficulties which remain in conventional theory and its associated Standard Model. An outline of the present revised theory is then given in Section 4, and its potentialities are presented in Section 5. A number of fundamental applications and new consequences of the same theory are finally summarized in Sections 6 and 7.

2 Quantization of the field equations

As stated by Schiff [2] among others, Maxwell's equations are used as a guideline for proper interpretation of conventional quantum electrodynamical theory. To convert in an analogous way the present extended field equations into their quantum electrodynamical counterpart, the most complete way would imply that the quantum conditions are included already from the outset.

In this treatise, however, a simplified procedure is applied, by first determining the general solutions of the basic field equations, and then imposing the relevant quantum conditions afterwards. This is at least justified by the fact that the quantized electrodynamic equations become identically equal to the original equations in which the potentials and currents are merely replaced by their expectation values, as shown by Heitler [3]. The result of such a procedure should therefore not be too far from the truth, by using the most probable trajectories and states in a first approximation.

3 Difficulties in conventional theory

As pointed out by Quigg [4] among others, the guiding principle of the Standard Model in theoretical physics is that its equations are symmetrical, and this does not permit masses for leptons and quarks. Such a feature also reveals itself in the symmetry of the conventional field equations of QED in which there are vanishing divergences of both the electric and magnetic fields in the vacuum, as given e.g. by Schiff [2].

In the Dirac wave equation of a single particle like the electron, the problem of nonzero mass and charge is circumambulated by introducing given values of its mass m_e and charge e. With an electrostatic potential ϕ and a magnetic vector potential $\mathbf{A}$, the equation for the relativistic wave function has the form

$$\alpha_0 m_e c\Psi + \boldsymbol{\alpha} \cdot [(\hbar/i)\nabla\Psi - (e/c)\mathbf{A}\Psi] + e\phi\Psi = -\frac{\hbar}{ic}\frac{\partial}{\partial t}\Psi \quad (1)$$

where α_i are the Dirac matrices given e.g. by Morse and Feshbach [5].

To fulfill the demand of a nonzero particle mass, the symmetry of the field equations has to be *broken*. One such possibility was worked out in the mid 1960s by Higgs [6] among others. From the corresponding equations a Higgs particle was predicted which should have a nonzero rest mass. Due to Ryder [7] the corresponding Lagrangian then takes the form

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \left|\left(\partial_\mu + icA_\mu\right)\phi\right|^2 - m^2\phi^*\phi - \lambda(\phi^*\phi)^2 \quad (2)$$

where ϕ represents a scalar field, A_μ a vector field, and $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$ is the electromagnetic field tensor. The quantity m further stands for a parameter where $m^2 < 0$ in the case of *spontaneous symmetry breaking*, and the parameter λ is related to a minimized potential. The symmetry breaking is due to the two last terms of the Lagrangian (2). The latter is *nonlinear* in its character, and corresponds to a deduced relation for the minimum of the vacuum potential. Experimental confirmation of this mechanism does not rule out the applicability of the present theory to the problem areas treated in this paper.

3.1 Steady states

Conventional theory based on Maxwell's equations in the vacuum is symmetric in respect to the field strengths $\mathbf{E}$ and $\mathbf{B}$. In the absence of external sources, such as for a self-consistent particle-like configuration, the charge density $\bar{\rho}$, div$\mathbf{E}$ and curl$\mathbf{B}$ all vanish. Then there is no scope for a local nonzero energy density in a steady state which would otherwise be the condition for a particle configuration having a nonzero rest mass. This is consistent with the statement by Quigg [4] that the symmetric conventional field equations do not permit masses for leptons and quarks.

The fundamental description of a charged particle is in conventional theory deficient also in the respect that an equilibrium cannot be maintained by the classical electrostatic forces, but has been assumed to require extra forces of a non-electromagnetic origin, as proposed e.g. by Heitler [3] and Jackson [8]. In other words, the electron would otherwise "explode" under the action of its electric self-charge.

The electron behaves like a point charge with a very small radius. Standard theory is confronted with the infinite self-energy of such a system. A quantum electromagnetic renormalization procedure has then been applied to yield a finite result, by adding an infinite ad hoc term to the Lagrangian, such as to obtain a finite result from the difference between two "infinities" [7]. Even if such a procedure has turned out to be successful, it can be questioned from the logical and physical points of view.

3.2 Wave modes

In a state of explicit time dependence, the conventional symmetric wave equations by Maxwell in the vacuum with vanishing electric and magnetic field divergences can be recast in terms of a Hertz vector $\mathbf{\Pi}$, as described by Stratton [9] and Halln [10] among others. These equations result in two partial solutions, $\mathbf{\Pi}_1$ and $\mathbf{\Pi}_2$, denoted as an electric and a magnetic type which are given by the fields

$$\mathbf{E_1} = \nabla(\mathrm{div}\mathbf{\Pi}_1) - (1/c^2)\partial^2\mathbf{\Pi}_1/\partial t^2 \quad (3)$$

$$\mathbf{B_1} = (1/c^2)\mathrm{curl}(\partial\mathbf{\Pi}_1/\partial t) \quad (4)$$

and

$$\mathbf{E_2} = -\mu_0\mathrm{curl}(\partial\mathbf{\Pi}_2/\partial t) \quad (5)$$

$$\mathbf{B_2} = \mu_0\nabla(\mathrm{div}\mathbf{\Pi}_2) - (\mu_0/c^2)\partial^2\mathbf{\Pi}_2/\partial t^2. \quad (6)$$

Here $c^2 = 1/\mu_0\epsilon_0$ with μ_0 denoting the magnetic permeability and ϵ_0 the dielectric constant in the vacuum. Using the results obtained from equations (3)-(6) and given in current literature, the integrated angular momentum in the direction of propagation (spin) can be evaluated for plane, cylindrical, and spherical wave modes. This is made in terms of the electromagnetic momentum density

$$\mathbf{g} = \epsilon_0\mathbf{E}\times\mathbf{B} = \frac{1}{c^2}\mathbf{S} \quad (7)$$

where $\mathbf{S}$ is the Poynting vector, and of the density

$$\mathbf{s} = \mathbf{r}\times\frac{\mathbf{S}}{c^2} \quad (8)$$

with $\mathbf{r}$ standing for the radius vector. The results are summarized as described by the author [11]:

- For plane waves propagating in the direction of a rectangular frame (x, y, z) the field components E_z and B_z vanish as well as the spin. A three-dimensional disturbance of arbitrary shape at a given instant can in principle be constructed by Fourier analysis from a spectrum of plane waves. At later instants, however, such a disturbance would rapidly disintegrate [9].
- Cylindrical geometry has the advantage of providing a starting point for waves which propagate with conserved shape in a defined direction like a photon, at

the same time as it can have limited dimensions in the transverse directions under certain conditions. With an elementary wave form $f(r)\exp[i(-\omega t + kz + n\varphi)]$ in a cylindrical frame (r, φ, z) with z in the direction of propagation, the dispersion relation becomes

$$K^2 = (\omega/c)^2 - k^2 \tag{9}$$

This leads to local spin densities s_{z1} and s_{z2} of equation (8) in respect to the z axis where

$$|s_{z1}| \text{ and } |s_{z2}| \propto K^2 n\,[J_n(Kr)]^2 \sin 2n\varphi \tag{10}$$

for the two types of equations (3)-(6), and with $J_n(Kr)$ as Bessel functions. Consequently, the local contribution to the spin vanishes both when $n = 0$ and $K = 0$. With nonzero n and K the total integrated spin also vanishes.

- When considering spherical waves which propagate along r in a spherical frame (r, θ, φ) of unbounded space at the phase velocity $\omega/k = c$ with a periodic variation $\exp(in\varphi)$, the field components are obtained in terms of associated Legendre functions, spherical Bessel functions, and factors $\sin(n\varphi)$ and $\cos(n\varphi)$ [9]. The asymptotic behavior of the components of the momentum density (7) then becomes

$$g_r \propto 1/r^2 \quad g_\theta \propto 1/r^3 \quad g_\varphi \propto 1/r^3 \tag{11}$$

The momentum g_r along the direction of propagation is the remaining one at large distances r for which the spin thus vanishes. From the conservation of angular momentum there is then no integrated spin in the near-field region as well. This is confirmed by its total integrated value.

From these results is thus shown that the conventional symmetric equations by Maxwell in the vacuum, and the related equations in quantized field theory, do not become reconcilable with a physically relevant photon model having nonzero spin.

In addition, a conventional theoretical concept of the photon as given by equations (3)-(6) cannot account for the needle-like behavior proposed by Einstein and being required for knocking out an atomic electron in the photoelectric effect. Nor can such a concept become reconcilable with the dot-shaped marks which occur at the screen of two-slit experiments from individual photon impacts, as observed e.g. by Tsuchiya et al. [12].

4 An outline of present revised theory

As stated in the introduction, the present theory is based on the hypothesis of a nonzero electric charge density in the vacuum. The detailed evaluation of the basic concepts of this theory has been reported by the author [13, 14] and is shortly outlined here. The general four-dimensional Lorentz invariant form of the corresponding Proca-type field equations reads

$$\left(\frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right) A_\mu = \mu_0 J_\mu, \quad \mu = 1, 2, 3, 4 \tag{12}$$

where

$$A_\mu = \left(\mathbf{A}, \frac{i\phi}{c}\right) \tag{13}$$

with $\mathbf{A}$ and ϕ standing for the magnetic vector potential and the electrostatic potential in three-space,

$$J_\mu = (\mathbf{j}, ic\bar{\rho}) = \bar{\rho}(\mathbf{C}, ic) \quad \mathbf{j} = \bar{\rho}\mathbf{C} = \epsilon_0(\mathrm{div}\mathbf{E})\mathbf{C} \tag{14}$$

and $\mathbf{C}$ being a velocity vector having a modulus equal to the velocity constant c of light, i.e. $\mathbf{C}^2 = c^2$. Consequently this becomes a *generalization* of Einsteins relativistic velocity limit. In three dimensions equation (12) in the vacuum results in

$$\frac{\mathrm{curl}\mathbf{B}}{\mu_0} = \epsilon_0(\mathrm{div}\mathbf{E})\mathbf{C} + \frac{\epsilon_0\partial\mathbf{E}}{\partial t} \tag{15}$$

$$\mathrm{curl}\mathbf{E} = -\frac{\partial\mathbf{B}}{\partial t} \tag{16}$$

$$\mathbf{B} = \mathrm{curl}\mathbf{A}, \ \mathrm{div}\mathbf{B} = 0 \tag{17}$$

$$\mathbf{E} = -\nabla\phi - \frac{\partial\mathbf{A}}{\partial t} \tag{18}$$

$$\mathrm{div}\mathbf{E} = \frac{\bar{\rho}}{\epsilon_0}. \tag{19}$$

These equations differ from the conventional form, by a nonzero electric field divergence in equation (19) and by the additional first term of the right-hand member in equation (15) which represents a "space-charge current density" in addition to the displacement current. Due to the form (14) there is a similarity between the current density and that by Dirac [5]. The extended field equations (15)-(19) are easily found also to become invariant to a gauge transformation. The same equations can further be derived from a Lagrangian density

$$\mathcal{L} = \frac{1}{2}\epsilon_0(\mathbf{E}^2 - c^2\mathbf{B}^2) - \bar{\rho}\phi + \mathbf{j}\cdot\mathbf{A}. \tag{20}$$

In this context special attention will be paid to steady states for which the field equations reduce to

$$c^2\mathrm{curlcurl}\mathbf{A} = -\mathbf{C}(\nabla^2\phi) = \frac{\bar{\rho}}{\epsilon_0}\mathbf{C} \tag{21}$$

and to wave modes for which

$$\left(\frac{\partial^2}{\partial t^2} - c^2\nabla^2\right)\mathbf{E} + \left(c^2\nabla + \mathbf{C}\frac{\partial}{\partial t}\right)(\mathrm{div}\mathbf{E}) = 0. \tag{22}$$

The main characteristic new features of the present theory can be summarized as follows:

- The hypothesis of a nonzero electric field divergence in the vacuum introduces an *additional* degree of freedom, leading to new physical phenomena. The associated nonzero electric charge density thereby acts somewhat like a "hidden variable".
- This also abolishes the symmetry between the electric and magnetic fields, and the field equations then obtain the character of *intrinsic linear symmetry breaking*.
- The theory is both Lorentz and gauge *invariant*.
- The velocity of light is no longer a scalar quantity, but is represented by a velocity *vector* of the modulus c.

5 Potentialities of present theory

Maxwell's equations in the vacuum, and their quantized counterparts, are heavily constrained. Considerable parts of this limitation can be removed by the present theory. Thus the characteristic features described in Section 4 debouch into a number of potentialities:

- The present linear field equations are characterized by an intrinsic broken symmetry. The Lagrangian (20) differs from the form (2) by Higgs. The present approach can therefore become an *alternative* to the Higgs concept of nonlinear spontaneous broken symmetry.
- In the theory by Dirac the mass and electric charge of the electron have been introduced as given parameters in the wave equation (1), whereas nonzero and finite masses and charges *result* from the solutions of the present field equations. This is due to the symmetry breaking of these equations which include *steady* electromagnetic states, not being present in conventional theory.
- As a further consequence of this symmetry breaking, the electromagnetic wave solutions result in photon models having *nonzero* angular momentum (spin), not being deducible from conventional theory, and being due to the current density $\mathbf{j}$ in equations (14) and (15) which gives a contribution to the momentum density (7).
- This broken symmetry also renders possible a *revised* renormalization process, providing an alternative to the conventional one in a physically more surveyable way of solving the infinite self-energy problem. This alternative is based on the nonzero charge density of equation (19).
- In analogy with conventional theory, a local momentum equation including a volume force term is obtained from vector multiplication of equation (15) by $\mathbf{B}$ and equation (16) by $\epsilon_0\mathbf{E}$, and adding the obtained equations. This results in a volume force density which does not only include the well-known electrostatic part $\bar{\rho}\mathbf{E}$, but also a *magnetic* part $\bar{\rho}\mathbf{C}\times\mathbf{B}$ not being present in conventional theory.

6 Fundamental applications

A number of concrete results are obtained from the present theory, as fundamental applications to models of leptons and photons and to be shortly summarized in this section.

6.1 An Electron Model

Aiming at a model of the electron at rest, a steady axisymmetric state is considered in a spherical frame (r, θ, φ) where $\mathbf{A} = (0, 0, A)$ and $\mathbf{j} = (0, 0, c\bar{\rho})$ with $C = \pm c$ representing the two spin directions. Equations (21) can be shown to have a general solution being derivable from a separable generating function

$$F(r,\theta) = CA - \phi = G_0 G(\rho,\theta) = G_0 R(\rho) T(\theta) \qquad (23)$$

where G_0 stands for a characteristic amplitude, $\rho = r/r_0$ is a normalized radial coordinate, and r_0 is a characteristic radial dimension. The potentials $\mathbf{A}$ and ϕ as well as the charge density $\bar{\rho}$ can be uniquely expressed in terms of F and its derivatives. This, in its turn, results in forms for the spatially integrated net values of electric charge q_0, magnetic moment M_0, mass m_0 obtained from the mass-energy relation by Einstein, and spin s_0.

A detailed analysis of the integrals of q_0 and M_0 shows that an electron model having nonzero q_0 and M_0 only becomes possible for radial functions $R(\rho)$ being divergent at the origin $\rho = 0$, in combination with a polar function $T(\theta)$ having top-bottom symmetry with respect to the midplane $\theta = \pi/2$. Neutrino models with vanishing q_0 and M_0 become on the other hand possible in three other cases. The observed point-charge-like behavior of the electron thus comes out as a consequence of the present theory, due to the requirement of a nonzero net electric charge.

The necessary divergence of the radial function R leads to the question how to obtain finite and nonzero values of all related field quantities. This problem can be solved in terms of a revised renormalization procedure, being an alternative to the conventional process of tackling the self-energy problem. Here we consider a generating function with the parts

$$R = \rho^{-\gamma} e^{-\rho}, \quad \gamma > 0 \qquad (24)$$

$$T = 1 + \sum_{\nu=1}^{n} \{a_{2\nu-1} \sin[(2\nu-1)\theta] + a_{2\nu}\cos(2\nu\theta)\}$$
$$= 1 + a_1 \sin\theta + a_2 \cos 2\theta + a_3 \sin 3\theta + \ldots \qquad (25)$$

where R is divergent at $\rho = 0$ and T is symmetric in respect to $\theta = \pi/2$. In the present renormalization procedure the lower radial limits of the integrals in (q_0, M_0, m_0, s_0) are taken to be $\rho = \epsilon$ where $0 < \epsilon \ll 1$. Further the concepts of first and second counter-factors are introduced and defined by the author [13,15], i.e.

$$f_1 = c_{rG}\epsilon = r_0 G_0 \quad f_2 = c_G \epsilon^2 = G_0 \qquad (26)$$

where c_{rG} and c_G are corresponding constants. Consequently all field quantities (q_0, M_0, m_0, s_0) then become nonzero and finite at small ϵ. This revised renormalization procedure implies that the "infinities" of the field quantities due to the divergence of R at $\rho = 0$ are outbalanced by the "zeros" of the counter-factors f_1 and f_2 .

The quantum conditions to be imposed on the general solutions are the spin condition

$$s_0 = \pm h/4\pi \tag{27}$$

of a fermion particle, the magnetic moment relation

$$M_0 m_0/q_0 s_0 = 1 + \delta_M \quad \delta_M = 1/2\pi f_0 = 0.00116 \tag{28}$$

given e.g. by Feynman [16], and the magnetic flux condition

$$\Gamma_{tot} = |s_0/q_0| \tag{29}$$

where Γ_{tot} stands for the total magnetic flux being generated by the electric current system.

From these conditions the normalized electric charge $q^* \equiv |q_0/e|$, with $q^* = 1$ as its experimental value, can be obtained in terms of the expansion (25). In the four-amplitude case (a_1, a_2, a_3, a_4) the normalized charge q^* is then found to be limited at large a_3 and a_4 in the a_3a_4-plane to a narrow "plateau-like" channel, localized around the experimental value $q^* = 1$ as shown by Lehnert and Scheffel [17] and Lehnert and Hk [18]. As final results of these deductions all quantum conditions and all experimentally relevant values of charge, magnetic moment, mass, and spin can thus be reproduced by the single choices of only two scalar free parameters, i.e. the counter-factors f_1 and f_2 [15,17,18]. This theory should also apply to the muon and tauon and corresponding antiparticles.

With correct values of the magnetic flux (29) including magnetic island formation, as well as the correct magnetic moment relation (28) including its Land factor, the plateau in a_3a_4-space thus contains the correct experimental value $q^* = 1$ of the elementary charge. There are deviations of only a few percent from this value within the plateau region. This could at a first sight merely be considered as fortunate coincidence. What speaks against this is, however, that changes in the basic conditions result in normalized charges which differ fundamentally from the experimental value, this within an accuracy of about one percent. Consequently, omission of the magnetic islands yields an incorrect value $q^* \approx 1.55$, and an additional change to half of the correct Land factor results in $q^* \approx 1.77$. That the correct forms of the magnetic flux and the magnetic moment become connected with a correct value of the deduced elementary charge, can therefore be taken as a strong support of the present theory. Moreover, with wrong values of the magnetic flux and Land factors, also the values of magnetic moment M_0 and mass m_0 would disagree with experiments.

The Lorentz invariance of the electron radius can be formally satisfied, in the case where this radius is allowed to shrink to that of a point charge. The obtained results can on the other hand also apply to the physically relevant situation of a small but nonzero radius of a configuration having an internal structure.

The configuration of the electron model can be prevented from "exploding" under the influence of its eigencharge and the electrostatic volume force $\bar{\rho}\mathbf{E}$. This is due to the presence of the magnetically confining volume force $\bar{\rho}\mathbf{C} \times \mathbf{B}$ [18].

6.2 A Photon Model

Cylindrical waves appear to be a convenient starting point for a photon model, due to the aims of a conserved shape in a defined direction of propagation and of limited spatial extensions in the transverse directions. In a cylindrical frame (r, φ, z) the velocity vector is here given by the form

$$\mathbf{C} = c(0, \cos\alpha, \sin\alpha) \tag{30}$$

where $\sin\alpha$ will be associated with the propagation and $\cos\alpha$ with the spin. In the case of axisymmetric waves, equation (22) yields

$$\omega = kv, \quad v = c(\sin\alpha) \tag{31}$$

for normal modes which vary as $f(r)\exp[i(-\omega t + kz)]$. The angle α should be constant since astronomical observations indicate that light from distant objects has no dispersion. The basic equations result in general solutions for the components of $\mathbf{E}$ and $\mathbf{B}$, in terms of a generating function

$$F(r, z, t) = E_z + (\cot\alpha)E_\varphi = G_0 G, \qquad G = R(\rho)\exp[i(-\omega t + kz)] \tag{32}$$

and its derivatives. The dispersion relation (31) shows that the phase and group velocities along the z direction of propagation are smaller than c. Not to get in conflict with the experiments by Michelson and Moreley, we then have to restrict ourselves to a condition on the spin parameter $\cos\alpha$, in the form

$$0 < \cos\alpha \ll 1 \quad v/c \approx 1 - \frac{1}{2}(\cos\alpha)^2. \tag{33}$$

From the normal mode solutions, wave-packets of narrow line width can be deduced, providing expressions for the correspondingly spectrally integrated field strengths $\bar{\mathbf{E}}$ and $\bar{\mathbf{B}}$. The latter are further used in spatial integrations which lead to a net electric charge $q = 0$ and net magnetic moment $M = 0$, as expected, and into a nonzero total mass $m \neq 0$ due to the mass-energy relation by Einstein, as well as to a nonzero spin $s \neq 0$ obtained from the Poynting vector and equation (8). There is also an associated very small photon rest mass $m_0 = m(\cos\alpha)$. Thus a nonzero spin and a nonzero photon rest mass become two sides of the same intrinsic property which vanishes with the parameter $\cos\alpha$, i.e. with div**E**. Due to the requirement of Lorentz invariance, a nonzero $\cos\alpha$ thus implies that a nonzero spin arises at the expense of a slightly reduced momentum and velocity in the direction of propagation. This is a consequence of the generalized Lorentz invariance in Section 4.

In this connection it has to be added that the alternative concept of a momentum operator $\mathbf{p} = -i\hbar\nabla$ has been applied to a massive particle in the Schrdinger equation [2]. As compared to the momentum density $\mathbf{g}$ of equation (7), however, the operator $\mathbf{p}$ leads to physically unrealistic transverse components for a cylindrically symmetric and spatially limited wave-packet model of the photon.

With a radial part of the generating function (32) being of the form

$$R(\rho) = \rho^{\gamma} e^{-\rho} \tag{34}$$

there are two options, namely the convergent case of $\gamma > 0$ and the divergent one of $\gamma < 0$. In the convergent case combination of the wave-packet solutions for a main wavelength λ_0 with the quantum conditions

$$m = h/c\lambda_0 \quad s = h/2\pi \tag{35}$$

results in an effective transverse photon radius

$$\hat{r} = \frac{\lambda_0}{2\pi(\cos\alpha)} \quad \gamma > 0. \tag{36}$$

In the divergent case a corresponding procedure has to be applied, but with inclusion of a revised renormalization being analogous to that applied to the electron. With the corresponding smallness parameter ϵ the effective photon radius then becomes

$$\hat{r} = \frac{\epsilon\lambda_0}{2\pi(\cos\alpha)} \quad \gamma < 0. \tag{37}$$

The results (36) and (37) can be considered to represent two modes. The first has relatively large radial extensions as compared to atomic dimensions, and for $\epsilon/(\cos\alpha) \leqslant 1$ the second mode leads to very small such extensions, in the form of "needle radiation". Such radiation provides explanations of the photoelectric effect, and of the occurrence of the dot-shaped marks on a screen in double-slit experiments [12]. The two modes (36) and (37) are based on the broken symmetry and have no counterpart in conventional theory. They can also contribute to an understanding of the two-slit experiments, somewhat in the sense of the Copenhagen school of Bohr and where an individual photon makes a transition between the present modes, in a form of "photon oscillations" including both a particle behavior and that of wave interference, as stated by the author [19]. Such oscillations would become analogous to those of neutrinos which have nonzero rest masses.

The nonzero electric field divergence further leads to insintric electric charges of alternating polarity within the body of an individual photon wave packet. This contributes to the understanding of electron-positron pair formation through the impact of an external electric field from an atomic nucleus or from an electron, as proposed by the author [20].

There is experimental evidence for the angular momentum of a light beam of spatially limited cross-section, as mentioned by Ditchburn [21]. This can be explained by contributions from its boundary layers, in terms of the present approach.

The wave equations of this theory can also be applied to cork-screw-shaped light beams in which the field quantities vary as $f(r)\exp[i(-\omega t + \bar{m}\varphi + kz)]$ and where the parameter $\bar{m}$ is a positive or negative integer. The dispersion relation then becomes

$$\omega/k = c(\sin\alpha) + (\bar{m}/kr)c(\cos\alpha). \tag{38}$$

The normal modes and their spectrally integrated screw-shaped configurations then result in a radially hollow beam geometry, as observed in experiments described by Battersby [22] among others.

For the W^+, W^- and Z^0 bosons, a Proca-type equation being analogous to that of the present theory can possibly be applied in the weak-field case. This would then provide the bosons with a nonzero rest mass, as an alternative to the Higgs concept.

With the present theory of the vacuum state as a background, fermions like the electron and neutrino, and bosons like the photon, could be taken as concepts with the following characteristics. The fermions can be made to originate from the steady-state field equations, represent "bound" states, and have an explicit rest mass being associated with their spin. This does not exclude that moving fermions also can have wave properties. The bosons originate on the other hand from the dynamic wavelike field equations, represent "free" states, and have an implicit rest mass associated with their spin. They occur as quantized waves of the field which describe the interaction between the particles of matter.

7 New consequences of present theory

Among the fundamental new consequences which only come out of the present theory and also strongly support its relevance, the following should be emphasized:

- Steady electromagnetic states lead to rest masses of leptons.
- A nonzero electronic charge is by necessity connected with a point-charge-like geometry.
- A deduced electronic charge agreeing with the experimental value results from correct forms of the magnetic moment and magnetic flux, but not from other forms.
- A confining magnetic force prevents the electron from "exploding" under the influence of its eigencharge.

- Electromagnetic waves and their photon models possess spin.
- There are needle-like wave solutions contributing to the understanding of the photoelectric effect and of two-slit experiments.
- The angular momentum of a light beam can be explained.

Submitted on February 7, 2012 / Accepted on February 17, 2012

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