Potentialities of Revised Quantum Electrodynamics

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The potentialities of a revised quantum electrodynamic theory (RQED) earlier established by the author are reconsidered, also in respect to other fundamental theories such as those by Dirac and Higgs. The RQED theory is characterized by intrinsic linear symmetry breaking due to a nonzero divergence of the electric field strength in the vacuum state, as supported by the Zero Point Energy and the experimentally confirmed Casimir force. It includes the results of electron spin and antimatter by Dirac, as well as the rest mass of elementary particles predicted by Higgs in terms of spontaneous nonlinear symmetry breaking. It will here be put into doubt whether the approach by Higgs is the only theory which becomes necessary for explaining the particle rest masses. In addition, RQED theory leads to new results beyond those being available from the theories by Dirac, Higgs and the Standard Model, such as in applications to leptons and the photon.

1 Introduction and background

The vacuum state is not merely that of an empty space. Its energy has a nonzero ground level, the Zero Point Energy, being derived from the quantum mechanical energy states given e.g. by Schiff [1]. An example on the related vacuum fluctuations was provided by Casimir [2] who predicted that two closely spaced metal plates will attract each other. This is due to the fact that only small wavelengths can exist in the spacing, whereas the full spectrum of fluctuations exerts a net force on the outsides of the plates. The Casimir force was first demonstrated experimentally by Lamoreaux [3]. It implies that the vacuum fluctuations generate a real physical pressure and pressure gradient. Part of the quantum fluctuations also carry electric charges, as pointed out e.g. by Abbot [4]. The observed electron-positron pair formation from an energetic photon further indicates that electric charges can be created out of an electrically neutral state.

These established facts form the starting point of a revised quantum electrodynamic (RQED) theory by the author [5]. The theory is thus based on the hypothesis of a nonzero electric field divergence, $\operatorname{div}\mathbf{E} \neq 0$, in the vacuum. At the same time there is still a vanishing magnetic field divergence, $\operatorname{div}\mathbf{B} = 0$, due to the experimental fact that no magnetic monopoles have so far been observed. A nonzero electric field divergence has the following fundamental consequences [5]:

- The symmetry between the electric and magnetic fields **E** and **B** is *broken*.
- The nonzero electric charge density of a configuration with internal structure can both lead to a *net* integrated charge, and to *intrinsic charges* of both polarities.
- There exist *steady* electromagnetic states in the vacuum for which the energy density of the electromagnetic field gives rise to nonzero *rest masses* of corresponding particle models.

In the following treatise the basic field equations of RQED theory are first shortly described in Section 2. This is followed in Section 3 by a comparison to the related theories by Dirac as summarized by Morse and Feshbach [6], and that by Higgs [7]. The features and potentialities of RQED theory have earlier been described by the author [5, 8]. In Section 4 some complementary points will be presented, with special emphasis on results obtained beyond the Standard Model and not being deducible from other theories.

2 Basic field equations of Revised Quantum Electrodynamics

In four-dimensional representation the electromagnetic field equations have the general form

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

with the four-potentials $A_\mu = (\mathbf{A}, i\phi/c)$, $\mathbf{A}$ and ϕ as the magnetic vector potential and the electrostatic potential in three-space, and the four-current

$$J_\mu = (\mathbf{j}, ic\bar{\rho}) \tag{2}$$

with $\mathbf{j}$ and $\bar{\rho}$ as electric current density and electric charge density in three-space. The form (1) is obtained from the original set of equations through a gauge transformation in which the Lorentz condition

$$\operatorname{div}\mathbf{A} + \frac{1}{c^2}\frac{\partial\phi}{\partial t} = 0 \tag{3}$$

is imposed.

The source term due to the four-current (2) in the right-hand member of (1) has to satisfy the Lorentz invariance. This implies that

$$\mathbf{j}^2 - c^2\bar{\rho}^2 = const = 0 \tag{4}$$

when J_μ is required to vanish with the charge density $\bar{\rho}$. This finally results in a four-current

$$J_\mu = \bar{\rho}\,(\mathbf{C}, ic) \tag{5}$$

where

$$\mathbf{C}^2 = c^2 \tag{6}$$

and $\mathbf{C}$ is a velocity vector with a modulus equal to the velocity constant c of light. Concerning (6) two points should be observed [5]:

- The vector $\mathbf{C}$ both includes the case of a plane wave propagating at the scalar velocity c, and three-dimensional cases such as those of a cylindrical wave where $\mathbf{C}$ has at least two spatial components. In this way (6) can be considered as an *extension* of the Lorentz invariance to three dimensions.
- Equation (6) is quadratic and leads to two solutions. These represent the two resulting *spin* directions.

In a three-dimensional representation the field equations in the vacuum now become

$$\frac{\operatorname{curl}\mathbf{B}}{\mu_0} = \varepsilon_0\,(\operatorname{div}\mathbf{E})\,\mathbf{C} + \varepsilon_0\frac{\partial\mathbf{E}}{\partial t} \tag{7}$$

$$\operatorname{curl}\mathbf{E} = -\frac{\partial\mathbf{B}}{\partial t} \tag{8}$$

where

$$\mathbf{B} = \operatorname{curl}\mathbf{A} \qquad \operatorname{div}\mathbf{B} = 0 \tag{9}$$

$$\mathbf{E} = -\nabla\phi - \frac{\partial\mathbf{A}}{\partial t} \qquad \operatorname{div}\mathbf{E} = \frac{\bar{\rho}}{\varepsilon}. \tag{10}$$

These equations are gauge invariant, as in all cases where Maxwell's equations also include source terms.

The basic features of the RQED field equations are thus specified and summarized by the following points:

- The abolished symmetry between the electric and magnetic fields leads to equations having the character of *intrinsic linear* symmetry *breaking*.
- The equations are both Lorentz and gauge *invariant*.
- There is a *source* given by the "space-charge current density" of the first term in the right-hand member of (7). Through the nonzero electric field divergence this form introduces an additional degree of freedom, leading to new physical phenomena.
- Electromagnetic *steady* states with corresponding nonzero rest masses occur on account of (7).
- *New* and *modified* wave modes arise from the extended form (6) of Lorentz invariance.
- There is full symmetry between the solutions of positive and negative polarity, thereby realizing particle models for matter as well as for *antimatter*.

As described by Schiff [1] among others, Maxwell's equations are used as a guideline for proper interpretation of conventional quantum electrodynamical theory. Thereby Heitler [9] has shown that the quantized electrodynamic equations become identical with the original classical equations in which the electromagnetic potentials and currents merely become replaced by their quantum mechanical *expectation* values. In an analogous way, this also applies to the present RQED theory.

2.1 Steady electromagnetic states

As an example on steady electromagnetic states, a particle-shaped axisymmetric configuration is now considered in a spherical frame (r, θ, φ) with a current density $j = (0, 0, C\bar{\rho})$ and a magnetic vector potential $\mathbf{A} = (0, 0, A)$. Here $C = \pm c$ represents the two spin directions. From equations (7)–(10) with $\partial/\partial t = 0$, $\partial/\partial\varphi = 0$, $\rho = r/r_0$ and r_0 standing for a characteristic radial dimension, the result becomes [5]

$$CA = -\left(\sin^2\theta\right) DF \tag{11}$$

$$\phi = -\left[1 + \left(\sin^2\theta\right) D\right] F \tag{12}$$

$$\bar{\rho} = -\frac{\varepsilon_0}{r_0^2\rho^2} D\left[1 + \left(\sin^2\theta\right) D\right] F \tag{13}$$

where

$$\begin{gathered} D = D_\rho + D_\theta \\ D_\rho = -\frac{\partial}{\partial\rho}\left(\rho^2\frac{\partial}{\partial\rho}\right) \qquad D_\theta = -\frac{\partial^2}{\partial\theta^2} - \frac{\cos\theta}{\sin\theta}\frac{\partial}{\partial\theta} \end{gathered} \tag{14}$$

and there is a separable generating function

$$\begin{gathered} F\,(r,\theta) = CA - \phi = G_0 \cdot G\,(\rho,\theta) \\ G\,(\rho,\theta) = R\,(\rho)\cdot T\,(\theta)\,. \end{gathered} \tag{15}$$

With equations (11)–(15) the net electric charge q_0, magnetic moment M_0, rest mass m_0, and integrated spin s_0 are then given by

$$q_0 = 2\pi\varepsilon_0 r_0 G_0 J_q \tag{16}$$

$$M_0 = \pi\varepsilon_0 C r_0^2 G_0 J_M \tag{17}$$

$$m_0 = \frac{\pi\varepsilon_0}{c^2} r_0 G_0^2 J_m \tag{18}$$

$$s_0 = \frac{\pi\varepsilon_0 C}{c^2} r_0^2 G_0^2 J_s \tag{19}$$

where

$$J_k = \int_{\rho_k}^{\infty}\int_0^{\pi} I_k\, d\rho\, d\theta \qquad k = q, M, m, s \tag{20}$$

and I_k are differential expressions given in terms of the quantities and operators of equations (11)–(15). In the integrals (20) the radii $\rho_k = 0$ when G is convergent at $\rho = 0$, and $\rho_k \neq 0$

are small radii of circles centered at $\rho = 0$ when G is divergent at $\rho = 0$ and a special renormalisation procedure has to be applied.

The form (15) of generating function has four alternatives. When $R(\rho)$ is divergent at $\rho = 0$ and $T(\theta)$ has top-bottom symmetry, there is a nonzero net charge q_0 and magnetic moment M_0, leading to models of charged leptons. In the remaining three cases both q_0 and M_0 vanish, thereby leading to neutral leptons such as massive neutrinos.

In addition to the quantization leading to expectation values of the field vectors, relevant second quantization conditions have to be imposed on the forms (16)–(19). These concern the spin, the magnetic moment, and the total magnetic flux [5].

2.2 New and modified wave modes

Due to experimental evidence, a model representing the wave packet of an individual photon in the vacuum has to satisfy the following general requirements:

- It should have a preserved and spatially limited geometrical shape of a wave packet propagating in an undamped way and in a defined direction, even at cosmical distances.
- To limit its geometrical shape, no artificial boundaries are to be imposed on the solutions of the field equations.
- The angular momentum in the direction of propagation, the spin, should be nonzero and have the constant value $h/2\pi$.

The field equations (7)–(10) have solutions satisfying these requirements. This applies e.g. to cylindrical waves in a frame (r, φ, z) with z along the direction of propagation. For these waves the velocity vector has the form

$$\mathbf{C} = c\,(0, \cos\alpha, \sin\alpha) \tag{21}$$

with a constant angle α. Normal modes varying as $f(r)\exp[i[-\omega t + kz)]$ in an axisymmetric case lead to the dispersion relation

$$\omega = kv \qquad v = c\,(\sin\alpha) \tag{22}$$

having phase and group velocities equal to v. Expressions for the components of $\mathbf{E}$ and $\mathbf{B}$ are then obtained from the separable generating function. A wave packet of narrow line width at a main wavelength λ_0 is further formed from a spectrum of these elementary modes. This finally leads to spatially integrated quantities such as net electric charge q, magnetic moment M, total mass m, and total spin s_z. The result is as follows:

- Both q and M vanish.
- There is a finite nonzero spin

$$\mathbf{s} = \mathbf{r} \times \frac{\mathbf{S}}{c^2} \qquad \mathbf{S} = \mathbf{E} \times \mathbf{B}/\mu_0 \tag{23}$$

where $\mathbf{r}$ is the radius vector, $\mathbf{S}$ the Poynting vector, and $s_z = h/2\pi$ for the component of $\mathbf{s}$ in the z direction.

- A finite mass

$$m = m_0/\,(\cos\alpha) \tag{24}$$

is obtained where m_0 stands for a nonzero but very small rest mass.

This solution leads to a characteristic radial dimension $\hat{r}$ for two modes given by

$$\hat{r} = \frac{\lambda_0}{2\pi\,(\cos\alpha)} \begin{cases} 1 & \text{(25a)} \\ \varepsilon & \text{(25b)} \end{cases}$$

where (25a) refers to a convergent generating function, and (25b) to a generating function which is divergent at $r = 0$ and where a special renormalisation procedure has to be applied.

The phase and group velocities of (22) are smaller than the velocity constant c. Still this difference from c can become small enough to be *hardly distinguishable*. An example can be given by $\sin\alpha = 1 - \delta$, $0 < \delta \ll 1$, $\varepsilon = \cos\alpha$, $0 < \varepsilon \ll 1$, and $\lambda_0 = 3 \times 10^{-7}$ m for a main wavelength in the visible range. When $\delta = 10^{-10}$ this yields characteristic radii of about 3×10^{-3} m and 5×10^{-7} m due to equations (25a) and (25b).

3 Relations to other fundamental theories

It has further to be established how the present RQED approach is related to such fundamental theories as that by Dirac [6] and by Higgs [7] with the associated Standard Model of elementary particles.

3.1 The theory by Dirac

To bring wave mechanical theory into harmony with the theory of relativity, Dirac adopted a new wave equation. Then it need not to be *assumed* that the electron is spinning or turning on its axis. According to the theory the electron will have an internal angular momentum (spin), and an associated magnetic moment. In fact there are four wave functions and corresponding matrices instead of one. These alternatives thus correspond to two spin directions, and to the two possibilities of matter and antimatter, such as in the form of the electron and the positron.

As seen from the previous sections, the present RQED theory is in full correspondence with that by Dirac, in including the two spin directions as well as particles and antiparticles. But the net elementary charge, e, and the finite electron rest mass, m_e, are only included as given and assumed parameters in the theory by Dirac, whereas these quantities are *deduced* from the field equations of RQED. The latter theory also leads to other new results beyond those being available from that by Dirac.

3.2 The theory by Higgs

The Standard Model of the theory on elementary particles is based on the source-free solutions of the field equations in the vacuum as an empty space, i.e. (1) with a vanishing right-hand member. This leads to the Hertz equations having a vanishing electric field divergence, and it results in massless particles, in contradiction with their experimentally confirmed massive counterparts.

To resolve this contradiction, Higgs [7] proposed a *spontaneous nonlinear* mechanism of symmetry *breaking* by which an unstable boson of unspecified but large nonzero rest mass is formed, having vanishing spin and electric charge. The Higgs boson then decays into a whole succession of massive elementary particles.

During many years attempts have been made to find the Higgs boson. Finally the highly advanced and imposing experiments performed by the projects ATLAS [10] and CMS [11] at CERN have bebouched into the important confirmation of an existing unstable Higgs-like boson. The latter has been found to be characterized by vanishing electric charge and spin, combined with a rest mass of about 125 GeV. It was also observed to decay rapidly into successions of particles with smaller nonzero rest masses.

However, it could here be put into doubt whether this important experimental result provides a unique confirmation of the theory by Higgs, or if the theory described in Section 2 of this paper could as well explain the results without reference to the theory by Higgs. This question can be divided into two parts, i.e. the formation of a Higgs-like particle, and its decay. The first part thus concerns formation of a particle of mass in the range of 125 GeV, having vanishing charge and spin. Equations (11)–(15) imply that massive particles can be created already from the *beginning* by the intrinsic linear broken symmetry mechanism of RQED. Among the obtained solutions there is one which is expected to become unstable, having an unspecified but nonzero and large rest mass, as well as vanishing charge and spin [12]. Such a particle of mass 125 GeV can thus be predicted. Concerning the second part of the raised question, the resulting particle would, as in all earlier known cases, decay into several other massive particles in a way being independent of and not being unique for the Higgs mechanism. In this connection it might at a first sight be argued that the Higgs-like particle obtained from RQED is not identical with that considered by Higgs. This would, however, lead to the unlikely situation of two particles having the same basic and initial data of mass, charge and spin and resulting into the same decay processes, but still not being identical.

There may finally exist a certain similarity between the source of the Higgs field and that of the Zero Point Energy of RQED.

4 New results beyond other approaches

There are results from RQED which are not deducible from the Standard Model and other fundamental theories, as being demonstrated here by a number of examples.

4.1 Models of leptons

The field equations (7)–(10) in a steady state $\partial/\partial t = 0$ lead to new results and solutions:

- Charged lepton models arise from a divergent generating function and result in a point-charge-like geometry of *small* radial dimensions, such as that of the electron.
- A *deduced* elementary electric net charge is obtained. It is located within a *narrow* parameter channel situated around the experimental value, e, and having a width of only a few percent of e.
- Through a revised renormalisation process all relevant quantum conditions and all experimental values of charge, magnetic moment, rest mass, and spin can be reproduced by the choice of *only two* free scalar parameters, the so called counter-factors.
- The magnetic field contribution to equations (7)–(10) *prevents* charged leptons from "exploding" under the action of their electrostatic eigenforce.
- There are intrinsic electric charges of both polarities in leptons, each being about an order of magnitude larger than the net elementary charge e. It results in a Coulomb interaction force between these particles, being about two orders of magnitude larger than that due to the net charge. If these conditions would also hold for quarks, the total Coulomb force would become *comparable* and *similar* to the short-range interaction of the strong force [13]. This raises the question whether the intrinsic charge force will interfere with the strong force, or even become identical with it.

4.2 Model of the photon

In the time-dependent state of wave phenomena, equations (7)–(10) yield the following results:

- The Standard Model corresponds to a vanishing right-hand member of (1), and leads to the set of Hertz equations with a vanishing electric field divergence. In its turn, this gives rise to a vanishing photon spin as obtained from (23) and its quantized equivalent [5, 14]. Due to RQED theory there is on the other hand a photon model based on the extended relativistic forms of equations (6), (21) and (22), leading to a nonzero spin and an associated nonzero but very small rest mass [5, 14]. Thereby the spin of a photon wave packet does not merely have to be assumed in general terms, but becomes *deduced*. The spin occurs at the expense of a small reduction of the phase and group velocities in the direction of propagation.
- The needle-like photon model represented by equations (25a) and (25b) contributes to the *understanding* of the photoelectric effect and of two-slit experiments, with their wave-particle dualism.

- The RQED theory on screw-shaped wave modes is consistent with observed *hollow* geometry of corks-crew-shaped light beams [5].
- The nonzero electric field divergence and its intrinsic electric charges of alternating polarity also contributes to the understanding of electron-positron *pair formation* from an electrically neutral and energetic photon.

5 Conclusions

The present revised quantum electrodynamic theory includes the results of earlier fundamental theories, such as that by Dirac on electron spin and antimatter, and that by Higgs on massive elementary particles. It could thus be put into doubt whether the theory by Higgs becomes necessary for explaining the particle rest masses. In addition, the present theory leads to new results beyond those available from these and other so far established fundamental theories, as well as from the Standard Model in general.

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