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Review of Quantum Electromagnetodynamics

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Abstract

Several years ago, I suggested a quantum field theory which has many attractive features. (1) It can explain the quantization of electric charge. (2) It describes symmetrized Maxwell equations. (3) It is manifestly covariant. (4) It describes local four-potentials. (5) It avoids the unphysical Dirac string. Here I will review the ideas which led to my model of magnetic monopoles including my prediction of the second kind of electromagnetic radiation. I will present also the mathematical formalism. Moreover I will suggest an experiment to verify the second kind of electromagnetic radiation and point out a possible observation of this radiation by August Kundt in 1885. Finally, I will list the many and far-reaching consequences, if this radiation will be confirmed by future experiments.

1. Introduction

The discovery of a second kind of light would be a multi-dimensional scientific revolution. It would shake the foundations of modern physics in many ways. It would be experimental evidence of physics beyond the standard theory of particle physics. The standard theory includes the Weinberg-Salam theory from 1967/1968 [1] and quantum chromodynamics from 1973 [2]. The observation would require not only that the theory of quantum electrodynamics formulated in 1948/1949 [3] has to be extended. It would challenge also the Copenhagen interpretation of quantum mechanics formulated in 1927/1928 [4]. Furthermore, the new kind of light would violate the relativity principle of special relativity from 1905 [5] and would require a symmetrization of Maxwell's equations from 1873 [6].

In the second section, I will review the ideas which led to my model of magnetic monopoles. The third section suggests an experiment to verify the second kind of electromagnetic radiation. In the fourth section, I will present the mathematical formalism. The fifth section deals with a possible observation of the second kind of electromagnetic radiation by August Kundt in 1885 [7]. In the sixth section, I will list the many and far-reaching consequences, if this radiation will be confirmed by future experiments.

2. The Model

The existence of the second kind of light was predicted theoretically. It can be understood by the following argumentation.

In 1948/1949 Tomonaga, Schwinger, Feynman, and Dyson introduced quantum electrodynamics [3]. It is the quantum field theory of electric and magnetic phenomena. This theory has one shortcoming. It cannot explain why electric charge is quantized, i.e. why it appears only in discrete units.

In 1931 Dirac [8] introduced the concept of magnetic monopoles. He has shown that any theory which includes magnetic monopoles requires the quantization of electric charge.

A theory of electric and magnetic phenomena which includes Dirac monopoles can be formulated in a manifestly covariant and symmetrical way if two four-potentials are used. Cabibbo and Ferrari in 1962 [9] were the first to formulate such a theory. It was examined in greater detail by later authors [10–15]. Within the framework of a quantum field theory one four-potential corresponds to Einstein's electric photon from 1905 [16] and the other four-potential corresponds to Salam's magnetic photon from 1966 [11].

In 1997 I have shown that the Lorentz force between an electric charge and a magnetic charge can be generated as follows [13]. An electric charge couples via the well-known vector coupling with an electric photon and via a new type of tensor coupling, named velocity coupling, with a magnetic photon. This velocity coupling requires the existence of a velocity operator.

For scattering processes this velocity is the relative velocity between the electric charge and the magnetic charge just before the scattering. For emission and absorption processes there is no possibility of a relative velocity. The velocity is the absolute velocity of the electric charge just before the reaction.

The absolute velocity of a terrestrial laboratory was measured by the dipole anisotropy of the cosmic microwave background radiation. This radiation was detected in 1965 by Penzias and Wilson [17], its dipole anisotropy was detected in 1977 by Smoot, Gorenstein, and Muller [18]. The mean value of the laboratory's absolute velocity is 371 km/s. It has an annual sinusoidal period because of the Earth's motion around the Sun with 30 km/s. It has also a daily sinusoidal period because of the Earth's rotation with 0.5 km/s.

According to my model from 1997 [13] each process that produces electric photons does create also magnetic photons. The cross-section of magnetic photons in a terrestrial laboratory is roughly one million times smaller than that of electric photons of the same energy. The exact value varies with time and has both the annual and the daily period.

As a consequence, magnetic photons are one million times harder to create, to shield, and to absorb than electric photons of the same energy.

The electric-magnetic duality is:

electric charge	— magnetic charge
electric current	— magnetic current
electric conductivity	— magnetic conductivity
electric field strength	— magnetic field strength
electric four-potential	— magnetic four-potential
electric photon	— magnetic photon
electric field constant	— magnetic field constant
dielectricity number	— magnetic permeability .

The refractive index of an insulator is the square root of the product of the dielectricity number and the magnetic permeability. Therefore it is invariant under a dual transformation. This means that electric and magnetic photon rays are reflected and refracted by insulators in the same way. Optical lenses cannot distinguish between electric and magnetic photon rays.

By contrast, electric and magnetic photon rays are reflected and refracted in a different way by metals. This is because electric conductivity and magnetic conductivity determine the reflection of light and they are not identical. The electric conductivity of a metal is several orders larger than the magnetic conductivity.

3. How to Verify the Magnetic Photon Rays

The easiest test to verify/falsify the magnetic photon is to illuminate a metal foil of thickness $1, \ldots, 100$ μm by a laser beam (or any other bright light source) and to place a detector (avalanche diode or photomultiplier tube) behind the foil. If a single foil is used, then the expected reflection losses are less than 1 %. If a laser beam of the visible light is used, then the absorption losses are less than 15 %. My model [13] predicts the detected intensity of the radiation to be

$$f = r(v/c)^4 \tag{1}$$

times the intensity that would be detected if the metal foil were removed and the laser beam would directly illuminate the detector. Here

$$\begin{aligned} v = v_{sun} + v_{earth} \cos(2\pi t/T_e) \cos(\varphi_{ec}) \\ + v_{rotation} \cos(2\pi t/T_{rot}) \cos(\varphi_{eq}) \end{aligned} \tag{2}$$

is the absolute velocity of the laboratory. The absolute velocity of the Sun as measured by the dipole anisotropy of the cosmic microwave background radiation is

$$v_{sun} = (371 \pm 0.5) \text{ km/s}. \tag{3}$$

The mean velocity of the Earth around the Sun is

$$v_{earth} = 30 \text{ km/s}. \tag{4}$$

The rotation velocity of the Earth is

$$v_{rotation} = 0.5 \text{ km/s} \cos(\varphi). \tag{5}$$

The latitude of the dipole with respect to the ecliptic is

$$\varphi_{ec} = 15^\circ. \tag{6}$$

The latitude of the dipole with respect to the equator (declination) is

$$\varphi_{eq} = 7^\circ. \tag{7}$$

The latitude of the laboratory is

$$\varphi = 48^\circ \tag{8}$$

for Strassbourg and Vienna and $\varphi = 43°$ for Madison. The sidereal year is

$$T_e = 365.24 \text{ days.} \quad (9)$$

A sidereal day is

$$T_{rot} = 23 \text{ h } 56 \text{ min.} \quad (10)$$

The zero point of the time, $t = 0$, is reached on December 9 at 0:00 local time. The speed of light is denoted by c. The factor for losses by reflection and absorption of magnetic photon rays of the visible light for a metal foil of thickness $1, \ldots, 100$ μm is

$$r = 0.8, \ldots, 1.0. \quad (11)$$

To conclude, my model [13] predicts the value $f \sim 10^{-12}$. Two experiments have been tried to confirm this prediction. The first one was tried in Vienna/Austria in February 2002. The second one was done in Madison/Wisconsin in March 2002. Both experiments yielded the value $f \sim 10^{-15}$. The result is not yet conclusive as background effects such as stray light cannot yet be excluded with certainty. If the result turns out to be correct, then it has to be explained why it is roughly 1000 times smaller than my prediction.

One possibility is that the prediction $f \sim 10^{-12}$ is strictly valid only for free charges. However, in condensed matter we have interactions of light with the electromagnetic field instead of interactions with free particles. In particle physics, too, we often do not have free charges. For example, the emission of synchrotron radiation occurs when the charged particles are within an external field. This means that the particles are off the mass shell. Here, too, the velocity coupling does not refer to the velocity of a charged particle. This is because the velocity of a particle which is not on the mass shell is not defined. The velocity coupling rather describes the velocity of the entire system, i.e. the centre of mass velocity of the particle and the field. Usually, this velocity is non-relativistic.

Another possibility is that the magnetic photon model has to be modified. Other versions of the magnetic photon model were suggested by Singleton [12] (where the magnetic photon has nonzero rest mass) and Carneiro [14] (where all interactions occur via vector coupling and where the photon propagator is more complicated).

4. Formalism

Let $J^\mu = (P, \mathbf{J})$ denote the electric four-current and $j^\mu = (\rho, \mathbf{j})$ the magnetic four-current. The well-known four-potential of the electric photon is $A^\mu = (\Phi, \mathbf{A})$. The four-potential of the magnetic photon is $a^\mu = (\varphi, \mathbf{a})$. Expressed in three-vectors the symmetrized Maxwell equations read,

$$\nabla \cdot \mathbf{E} = P, \quad (12)$$
$$\nabla \cdot \mathbf{B} = \rho, \quad (13)$$
$$\nabla \times \mathbf{E} = -\mathbf{j} - \partial_t \mathbf{B}, \quad (14)$$
$$\nabla \times \mathbf{B} = +\mathbf{J} + \partial_t \mathbf{E} \quad (15)$$

and the relations between field strengths and potentials are

$$\mathbf{E} = -\nabla\Phi - \partial_t \mathbf{A} - \nabla \times \mathbf{a}, \quad (16)$$
$$\mathbf{B} = -\nabla\varphi - \partial_t \mathbf{a} + \nabla \times \mathbf{A}. \quad (17)$$

The Lagrangian for a spin 1/2 fermion field Ψ of rest mass m_0, electric charge Q, and magnetic charge q within an electromagnetic field can be constructed as follows. By using the tensors

$$F^{\mu\nu} \equiv \partial^\mu A^\nu - \partial^\nu A^\mu, \quad (18)$$
$$f^{\mu\nu} \equiv \partial^\mu a^\nu - \partial^\nu a^\mu \quad (19)$$

the Lagrangian of the Dirac fermion within the electromagnetic field reads,

$$\begin{aligned}\mathcal{L} = &-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}f_{\mu\nu}f^{\mu\nu} + \bar{\Psi}i\gamma^\mu\partial_\mu\Psi \\ &- m_0\bar{\Psi}\Psi - Q\bar{\Psi}\gamma^\mu\Psi A_\mu - q\bar{\Psi}\gamma^\mu\Psi a_\mu \\ &+ Q\bar{\Psi}\gamma^5\sigma^{\mu\nu}u_\nu\Psi a_\mu + q\bar{\Psi}\gamma^5\sigma^{\mu\nu}u_\nu\Psi A_\mu. \quad (20)\end{aligned}$$

By using the Euler-Lagrange equations we obtain the Dirac equation

$$\begin{aligned}(i\gamma^\mu\partial_\mu - m_0)\Psi = (&Q\gamma^\mu A_\mu + q\gamma^\mu a_\mu \\ &- Q\gamma^5\sigma^{\mu\nu}u_\nu a_\mu - q\gamma^5\sigma^{\mu\nu}u_\nu A_\mu)\Psi. \quad (21)\end{aligned}$$

By introducing the four-currents

$$J^\mu = Q\bar{\Psi}\gamma^\mu\Psi - q\bar{\Psi}\gamma^5\sigma^{\mu\nu}u_\nu\Psi, \quad (22)$$
$$j^\mu = q\bar{\Psi}\gamma^\mu\Psi - Q\bar{\Psi}\gamma^5\sigma^{\mu\nu}u_\nu\Psi \quad (23)$$

the Euler-Lagrange equations yield the two Maxwell equations

$$J^\mu = \partial_\nu F^{\nu\mu} = \partial^2 A^\mu - \partial^\mu\partial^\nu A_\nu, \quad (24)$$
$$j^\mu = \partial_\nu f^{\nu\mu} = \partial^2 a^\mu - \partial^\mu\partial^\nu a_\nu. \quad (25)$$

Evidently, the two Maxwell equations are invariant under the $U(1) \times U'(1)$ gauge transformations

$$A^\mu \to A^\mu - \partial^\mu\Lambda, \quad (26)$$
$$a^\mu \to a^\mu - \partial^\mu\lambda. \quad (27)$$

Furthermore, the four-currents satisfy the continuity equations

$$0 = \partial_\mu J^\mu = \partial_\mu j^\mu. \quad (28)$$

The electric and magnetic field are related to the tensors above by

$$E^i = F^{i0} - \frac{1}{2}\varepsilon^{ijk} f_{jk} \tag{29}$$

$$B^i = f^{i0} + \frac{1}{2}\varepsilon^{ijk} F_{jk}. \tag{30}$$

Finally, the Lorentz force is

$$K^\mu = Q(F^{\mu\nu} + \frac{1}{2}\varepsilon^{\mu\nu\varrho\sigma} f_{\varrho\sigma})u_\nu + q(f^{\mu\nu} - \frac{1}{2}\varepsilon^{\mu\nu\varrho\sigma} F_{\varrho\sigma})u_\nu \tag{31}$$

where $\varepsilon^{\mu\nu\varrho\sigma}$ denotes the totally antisymmetric tensor. This formula for the Lorentz force is rather trivial for the classical theory. Non-trivial is that this formula can be applied to the quantum field theory. This becomes possible because of the introduction of the velocity coupling which includes a velocity operator and allows the definition of a force operator.

5. Possible Observation of Magnetic Photon Rays

In Strassbourg in 1885, August Kundt [7] passed sunlight through red glass, a polarizing Nicol, and platinized glass which was covered by an iron layer. The entire experimental setup was placed within a magnetic field. With the naked eye, Kundt measured the Faraday rotation of the polarization plane generated by the transmission of the sunlight through the iron layer. His result was a constant maximum rotation of the polarization plane per length of $418,000°/\text{cm}$ or $1°$ per 23.9 nm. He verified this result until thicknesses of up to 210 nm and rotations of up to 9°.

In one case, on a very clear day, he observed the penetrating sunlight for rotations of up to 12°. Unfortunately, he has not given the thickness of this particular iron layer he used. But if his result of a constant maximum rotation per length can be applied, then the corresponding layer thickness was ~ 290 nm.

Let us recapitulate some classical electrodynamics to determine the behavior of light within iron. The penetration depth of light in a conductor is

$$\delta = \frac{\lambda}{2\pi\gamma} \tag{32}$$

where the wavelength in vacuum can be expressed by its frequency according to $\lambda = 1/\sqrt{\nu^2\varepsilon_0\mu_0}$. The extinction coefficient is

$$\gamma = \frac{n}{\sqrt{2}}\left[-1 + \left(1 + \left(\frac{\sigma}{2\pi\nu\varepsilon_0\varepsilon_r}\right)^2\right)^{1/2}\right]^{1/2} \tag{33}$$

where the refractive index is $n = \sqrt{\varepsilon_r\mu_r}$. For metals we get the very good approximation

$$\delta \approx \left(\frac{1}{\pi\mu_0\mu_r\sigma\nu}\right)^{1/2}. \tag{34}$$

The specific resistance of iron is

$$1/\sigma = 8.7 \times 10^{-8}\ \Omega\text{m}, \tag{35}$$

its permeability is $\mu_r \geq 1$. For red light of $\lambda = 630$nm and $\nu = 4.8 \times 10^{14}$Hz we get the penetration depth

$$\delta = 6.9\ \text{nm}. \tag{36}$$

Only a small fraction of the sunlight can enter the iron layer. Three effects have to be considered.

(i) The red glass allows the penetration of about $\varepsilon_1 \sim 50$ % of the sunlight only.

(ii) Only $\varepsilon_2 = 2/\pi \simeq 64$ % of the sunlight can penetrate the polarization filter.

(iii) Reflection losses at the surface of the iron layer have to be considered. The refractive index for electric photon light is given by

$$\bar{n}^2 = \frac{n^2}{2}\left(1 + \sqrt{1 + \left(\frac{\sigma}{2\pi\varepsilon_0\varepsilon_r\nu}\right)^2}\right). \tag{37}$$

For metals we get the very good approximation

$$\bar{n} \simeq \sqrt{\frac{\mu_r\sigma}{4\pi\varepsilon_0\nu}}. \tag{38}$$

The fraction of the sunlight which is not reflected is

$$\varepsilon_3 = \frac{2}{1+\bar{n}} = \frac{2}{1 + \sqrt{\mu_r\sigma/(4\pi\varepsilon_0\nu)}} \tag{39}$$

and therefore $\varepsilon_3 \simeq 0.13$ for the system considered. Taken together, the three effects allow only $\varepsilon_1\varepsilon_2\varepsilon_3 \sim 4$ % of the sunlight to enter the iron layer.

The detection limit of the naked eye is 10^{-13} times the brightness of sunlight provided the light source is pointlike. For an extended source the detection limit depends on the integral and the surface brightness. The detection limit for a source as extended as the Sun (0.5° diameter) is $l_d \sim 10^{-12}$ times the brightness of sunlight. If sunlight is passed through an iron layer (or foil, respectively), then it is detectable with the naked eye only if it has passed not more than

$$(\ln(1/l_d) + \ln(\varepsilon_1\varepsilon_2\varepsilon_3))\delta \sim 170\ \text{nm}. \tag{40}$$

Reflection losses by haze in the atmosphere further reduce this value.

Kundt's observation can hardly be explained with classical electrodynamics. Air bubbles within the metal layers cannot explain Kundt's observation, because air does not generate such a large rotation. Impurities, such as glass, which do generate an additional rotation, cannot completely be ruled out as the explanation. However, impurities are not a likely explanation, because Kundt was able to reproduce his observation by using several layers which he examined at various places.

Quantum effects cannot explain the observation, because they decrease the penetration depth, whereas an increment would be required.

The observation may become understandable if Kundt has observed a second kind of electromagnetic radiation, the magnetic photon rays. I predict their penetration depth to be

$$\delta_m = \delta(c/v)^2 \sim 5 \text{ mm}. \tag{41}$$

To learn whether Kundt has indeed observed magnetic photon rays, his experiment has to be repeated.

6. Consequences

The observation of magnetic photon rays would be a multi-dimensional revolution in physics. Its implications would be far-reaching.

(1) The experiment would provide evidence of a second kind of electromagnetic radiation. The penetration depth of these magnetic photon rays is roughly one million times greater than that of electric photon light of the same wavelength. Hence, these new rays may find applications in medicine where X-ray and ultrasonic diagnostics are not useful. X-ray examinations include a high risk of radiation damages, because the examination of teeth requires high intensities of X-rays and genitals are too sensible to radiation damages. Examinations of bones and the brain may also become possible.

(2) The experiment would confirm the existence of a new vector gauge boson, Salam's magnetic photon from 1966 [11]. It has the same quantum numbers as Einstein's electric photon [16], i.e. spin of one, negative parity, zero rest mass, and zero charge. The vanishing rest mass for both the electric and the magnetic photon is required to satisfy the Dirac quantization condition of electric and magnetic charge.

(3) A positive result would provide evidence of an extension of quantum electrodynamics which includes a symmetrization of Maxwell's equations from 1873 [6].

(4) The experiment would provide indirect evidence of Dirac's magnetic monopoles from 1931 and the explanation of the quantization of electric charge [8]. This quantization is known since Rutherford's discovery of the proton in 1919 [19].

(5) My model describes both an electric current and a magnetic current, even in experimental situations which do not include magnetic charges. This new magnetic current has a larger specific resistance in conductors than the electric current. It may find applications in electronics.

(6) Dirac noticed in 1931 that the coupling constant of magnetic monopoles is much greater than unity [8]. This raises new questions concerning the perturbation theory, the renormalizability, and the unitarity of quantum field theories.

(7) The intensity of the magnetic photon rays should depend on the absolute velocity of the laboratory. The existence of the absolute velocity would violate Einstein's relativity principle of special relativity from 1905 [5]. It would be interesting to learn whether there exist further effects of absolute motion.

(8) The supposed non-existence of an absolute rest frame was the only argument against the existence of a luminiferous aether [5]. If the absolute velocity does exist, we have to ask whether aether exists and what its nature is.

(9) When in 1925 Heisenberg introduced quantum mechanics, he argued that motion does not exist in this theory [20]. This view is taken also in the Copenhagen interpretation of quantum mechanics formulated in 1927/1928 by Heisenberg and Bohr [4]. The appearance of a velocity operator in my model challenges this Copenhagen interpretation. Mathematically, the introduction of a velocity (and force) operator means that quantum mechanics has to be described not only by partial but also by ordinary differential equations.

(10) Magnetic photon rays may contribute to our understanding of several astrophysical and high energy particle physics phenomena where relativistic absolute velocities appear and where electric and magnetic photon rays are expected to be created in comparable intensities.

(11) Finally, the other interactions may show similar dualities. The new dual partners of the known gauge bosons would be the magnetic photon, the isomagnetic W- and Z-boson, and the chromomagnetic gluons. In 1999 I argued that the dual partner of the graviton would be the tordion [15]. This boson has a spin of three and is required by Cartan's torsion theory from 1922 [21] which is an extension of Einstein's general relativity from 1915 [22].

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