Paper 18

Dipole Model for the Photon and the Evans-Vigier Field

The fundamental magnetizing field of light, $\boldsymbol{B}^{(3)}$, is expressed in terms of vector cross products of oscillating electric and magnetic dipole moments of vacuum electromagnetic radiation. The consequences are developed with reference to a new dipole model of the photon recently suggested by Mac Gregor [16]. The similarities and differences in the two theories are analyzed briefly.

Key words: $\boldsymbol{B}^{(3)}$ Field, Dipole Model.

18.1 Introduction

The photon as particle is usually considered to be without mass: light, after all, is assumed to travel at the speed of light, which is c in the vacuum. The recent emergence [1—12] of the Evans-Vigier field $\boldsymbol{B}^{(3)}$ has shown, however, that this idea cannot be physically meaningful, essentially because $\boldsymbol{B}^{(3)}$ indicates a third degree of polarization which is forbidden for a massless particle [6]. The unphysical nature of a massless particle was first inferred by Wigner [13] who showed that the little group in such a case is *E(2)*. This is the Euclidean group of rotations and translations simultaneously taking place *in a plane*. Such a group has no physical meaning [14]. Therefore the idea of a massless particle is physically obscure in classical special relativity, but is paradoxically accepted by the contemporary majority. Since $\boldsymbol{B}^{(3)}$ is observable directly in magneto-optical phenomena, such as the inverse Faraday effect [15], Wigner's deduction receives experimental verification through $\boldsymbol{B}^{(3)}$. The existence of this field in the vacuum has now been inferred from the Hamiltonian principle of least action and from the Dirac equation [6], and it is therefore a new, fundamental, property of light. In consequence, the photon, as particle, is concomitant with physically meaningful field components in three polarizations, denoted by $\boldsymbol{B}^{(1)}$, $\boldsymbol{B}^{(2)}$ and $\boldsymbol{B}^{(3)}$ in a complex circular representation, (1), (2) and (3), of three dimensional space [6]. Two of these axes are transverse (perpendicular) to the direction of propagation and the third, (3), is longitudinal, meaning that $\boldsymbol{B}^{(3)}$ is an axial vector directed in the (3) axis.

The traditional view recognizes the existence of the conjugate product $\boldsymbol{B}^{(1)} \times \boldsymbol{B}^{(2)}$ in, for example, the inverse Faraday effect [15], but the all important extra inference,

$$\boldsymbol{B}^{(1)} \times \boldsymbol{B}^{(2)} = iB^{(0)}\boldsymbol{B}^{(3)*}, \qquad \boldsymbol{B}^{(2)} \times \boldsymbol{B}^{(3)} = iB^{(0)}\boldsymbol{B}^{(1)*}, \qquad \boldsymbol{B}^{(3)} \times \boldsymbol{B}^{(1)} = iB^{(0)}\boldsymbol{B}^{(2)*}, \tag{2.18.1}$$

was achieved only recently [1]. Here $\boldsymbol{B}^{(1)} = \boldsymbol{B}^{(2)*}$ is the complex magnetic plane wave in vacuo, $B^{(0)}$ the scalar amplitude of the magnetic flux density carried by the wave, and where $\boldsymbol{B}^{(3)} = \boldsymbol{B}^{(3)*}$ is a real, phase free, spin field. In the traditional view, $\boldsymbol{B}^{(3)}$ is unconsidered, the vacuum Maxwell equations are applied only to plane *waves*. Due to the Lie algebra [1], however, essentially the algebra of the *O(3)* rotation group, the very existence of the plane waves $\boldsymbol{B}^{(1)}$ and $\boldsymbol{B}^{(2)}$ means the existence of $\boldsymbol{B}^{(3)}$, which is real and

physical, and which magnetizes matter in the inverse Faraday effect [15]. The conjugate product $\boldsymbol{B}^{(1)} \times \boldsymbol{B}^{(2)}$ can also be interpreted in a meaningful, physical, way because $\boldsymbol{T}_V = -\boldsymbol{B}^{(1)} \times \boldsymbol{B}^{(2)}/\mu_0$ is the torque per unit volume carried by electromagnetic radiation in vacuo. This is pure imaginary, i.e., has no real part because the real angular momentum density of the radiation is constant (the angular momentum of one photon is $\hbar$) and therefore its real time derivative is zero. The quantity $\boldsymbol{T}_V/c$ is the antisymmetric part of the tensor of light intensity [4] a tensor whose scalar part is, in this notation,

$$I_0 = \frac{1}{c}|\boldsymbol{T}_V| = \frac{B^{(0)2}}{\mu_0 c}. \tag{2.18.2}$$

Therefore $\boldsymbol{B}^{(3)}$ and $\boldsymbol{T}_V$ can be expressed in terms of the S_3 Stokes parameter [3].

Although $\boldsymbol{T}_V$ is pure imaginary in the vacuum, it causes magnetization in the inverse Faraday effect [15] through the imaginary part of material hyperpolarizability, in the simplest case, one electron hyperpolarizability [6]. Therefore both $\boldsymbol{B}^{(3)}$ and $\boldsymbol{T}_V$ play a role in the correct, relativistic, treatment of the inverse Faraday effect, and this can be demonstrated from the principle of least action by using the relativistic Hamilton-Jacobi equation of one electron in the circularly polarized electromagnetic field. Therefore $\boldsymbol{B}^{(3)}$ is inferred both experimentally (through the observation [15] of the inverse Faraday effect) and theoretically (from the relativistic principle of least action).

In this Letter, the vacuum $\boldsymbol{B}^{(3)}$ field is expressed through conjugate products of the complex magnetic and electric dipole moments of the radiation in vacuo (Sec. 18.2). Section 18.3 compares this result with the theory of Mac Gregor [16], who has developed an interesting dipole formulation of the photon, both in terms of charge and mass.

18.2 Double Dipole Expressions for $B^{(3)}$

The field $\boldsymbol{B}^{(3)}$ emerges from the free space electromagnetic torque density as follows

$$\boldsymbol{B}^{(3)} = \frac{i\mu_0}{B^{(0)}}\boldsymbol{T}_V, \tag{2.18.3}$$

and although $\boldsymbol{T}_V$ has no real part, $\boldsymbol{B}^{(3)}$ is real and physical. Recently, Mac Gregor has developed a model of the photon based on the concept of symmetric particle-antiparticle excitation [16] of the vacuum state. The electrodynamic part of this model reduces to a picture of the photon as a rotating dipole with zero net charge. The Mac Gregor electric dipole rotates in the plane orthogonal to the axis of propagation, $\boldsymbol{e}^{(3)}$. Antecedents of this picture were traced [16] to Bateman [17], Bonnor [18], and J. J. Thomson [19]. Bonnor [18] added masses to the charges, and developed the theory in the context of special and general relativity, showing that the electromagnetic energy density of an electric dipole traveling at the speed of light is finite.

In this section, we develop an analogous theory for $\boldsymbol{B}^{(3)}$ in terms of magnetic and electric dipole moments of the vacuum radiation. The cyclic relations,

$$\boldsymbol{m}^{(1)} \times \boldsymbol{m}^{(2)} = i\mu_0 B^{(0)}\boldsymbol{m}^{(3)*}, \tag{2.18.4}$$

emerge directly from the *S.I.* relation,

$$\boldsymbol{m} = \frac{\boldsymbol{B}}{\mu_0}, \tag{2.18.5}$$

where $\boldsymbol{m}$ is a magnetic dipole moment. Therefore $\boldsymbol{m}^{(1)}$, $\boldsymbol{m}^{(2)}$ and $\boldsymbol{m}^{(3)}$ are magnetic dipole moments of the radiation *itself*, and should not be confused with material dipole moments in matter. The reason is that Eq. (2.18.4) is one for vacuum propagation of light.

A similar relation for electric dipole moments of the radiation can be deduced from the *S.I.* relation,

$$\boldsymbol{\mu} = \epsilon_0 V\boldsymbol{E}, \tag{2.18.6}$$

where V is the radiation volume and ϵ_0 the vacuum permittivity. Equation (2.18.6) follows directly from the relation between polarization and electric dipole moment density,

$$\boldsymbol{P} = \frac{\boldsymbol{\mu}}{V}. \tag{2.18.7}$$

If $\boldsymbol{E}^{(1)} = \boldsymbol{E}^{(2)*}$ is the electric field strength (V m^{-1}) of the vacuum plane wave, and $E^{(0)}$ its amplitude, we have [6],

$$\boldsymbol{B}^{(3)*} = \frac{1}{icE^{(0)}}\boldsymbol{E}^{(1)} \times \boldsymbol{E}^{(2)}, \tag{2.18.8}$$

and so

$$\boldsymbol{B}^{(3)*} = -i\frac{\epsilon_0}{\mu_0} \cdot \frac{1}{B^{(0)}}\frac{\boldsymbol{\mu}^{(1)}}{V} \times \frac{\boldsymbol{\mu}^{(2)}}{V}, \tag{2.18.9}$$

which expresses the Evans-Vigier field in terms of the cross product of electric dipole moment densities of the vacuum radiation itself.

18.3 Discussion

Equation (2.18.9) is an expression of the $\boldsymbol{B}^{(3)}$ field in terms of,

$$\boldsymbol{\mu}^{(1)} = \epsilon_0 V \frac{E^{(0)}}{\sqrt{2}} (\boldsymbol{i} - i\boldsymbol{j}) e^{i\phi}, \tag{2.18.10}$$

which is itself a traveling plane wave in the vacuum. An electric dipole moment can be analyzed in terms of positive and negative charges separated by a distance $\boldsymbol{r}$, and because the vector is rotating as the light beam propagates in the $\boldsymbol{e}^{(3)}$ axis, the $\boldsymbol{B}^{(3)}$ field is formed from this motion. The rotations of the positive and negative charges reinforce each other in the creation of the vacuum $\boldsymbol{B}^{(3)}$ by Eq. (2.18.9), and $\boldsymbol{B}^{(3)}$ itself is relativistically invariant. This classical analysis, which is a direct result of the vacuum Maxwell equations, is similar to that proposed by Mac Gregor [16], who points out that the classical electromagnetic field is always the result of the movement of charge by Ampère's hypothesis [20]. The simple analysis of Sec. (18.2) shows that the field can be expressed in terms of either magnetic or electric dipole moments, and therefore in terms of separated charges. The field amplitudes $E^{(0)}$ and $B^{(0)}$ are negative under charge conjugation, $\hat{C}$, [21], and in the quantized field the photon is also negative under $\hat{C}$,

$$\hat{C}(\gamma) = -\gamma . \tag{2.18.11}$$

Therefore the particulate photon is always concomitant in vacuo with $\hat{C}$ negative electric and magnetic fields and dipoles.

Equation (2.18.1) defines a novel magnetic field, $\boldsymbol{B}^{(3)}$ [6], the Evans-Vigier field, that has a physical existence in the vacuum orthogonal to the plane defined by $\boldsymbol{B}^{(1)}$ or $\boldsymbol{E}^{(1)}$; or by $\boldsymbol{m}^{(1)}$ for $\boldsymbol{\mu}^{(1)}$ in the circular basis [1—12],

$$\boldsymbol{e}^{(1)} \times \boldsymbol{e}^{(2)} = i\boldsymbol{e}^{(3)*}, \text{ et cyclicum,} \tag{2.18.12}$$

for three dimensional space [6]. The gauge group [22] of vacuum electrodynamics must in consequence [6,16] become *O(3)*, and fundamental gauge theory [6,22] leads directly to,

$$\boldsymbol{B}^{(3)*} = -i\frac{e}{\hbar}\boldsymbol{A}^{(1)} \times \boldsymbol{A}^{(2)} , \tag{2.18.13}$$

where $\boldsymbol{A}^{(1)} = \boldsymbol{A}^{(2)*}$ is the vector potential defined by,

$$\boldsymbol{B}^{(1)} = \nabla \times \boldsymbol{A}^{(1)}. \tag{2.18.14}$$

Equation (2.18.13) leads to the charge quantization condition [6],

$$\hbar\kappa = eA^{(0)}, \tag{2.18.15}$$

where $\hbar\kappa$ is the magnitude of the linear momentum in vacuo of the free photon, and where $A^{(0)}$ is the scalar magnitude of $\boldsymbol{A}^{(1)}$. Equation (2.18.15) [6] shows that the magnitude (e) of the electronic charge is also the scaling factor of the *O(3)* gauge group, and is defined by the ratio $\hbar\kappa/A^{(0)}$. This is a direct consequence of the existence of $\boldsymbol{B}^{(3)}$ through Eqs. such as (2.18.1) or (2.18.9), equations which spring from the three dimensional nature of space itself.

In Mac Gregor's terminology [16], e and $A^{(0)}$ form a neutral pair, and are both $\hat{C}$ negative quantities. Therefore the conventional view [20—22] that the photon is *uncharged* is narrowly defined, both in Mac Gregor's analysis, and in that given here.

The physical interpretation of Eq. (2.18.10) shows the clockwise rotation of $\boldsymbol{\mu}^{(1)}$ for a right circularly polarized electromagnetic field in vacuo, propagating towards the observer [20] with negative helicity. One tip of the rotating dipole describes a circle around the origin if we neglect the forward motion of the wave. At the origin, the other tip of the dipole is fixed. If the moving tip is thought of as negatively charged, that charge moves on a helix as the electromagnetic wave propagates, and this is precisely analogous with the current in a solenoid. It is clear that the Evans-Vigier field is induced in the propagation axis (*Z*) as a result of this motion of $\boldsymbol{\mu}^{(1)}$. If the motion is anticlockwise, $\boldsymbol{B}^{(3)}$ reverses sign and the wave becomes left circularly polarized with positive helicity [20]. This is represented mathematically by,

$$\boldsymbol{\mu}^{(1)} = \frac{\mu^{(0)}}{\sqrt{2}}(\boldsymbol{i} \mp i\boldsymbol{j})e^{i\phi}, \qquad \phi := \omega t - \boldsymbol{\kappa}\cdot\boldsymbol{r},$$

$$\mu^{(0)} := \epsilon_0 V E^{(0)}, \tag{2.18.16}$$

where ω is the angular frequency of rotation at an instant t, and $\boldsymbol{\kappa}$ is the wave vector at position $\boldsymbol{r}$. Equation (2.18.16) represents a rotating and simultaneously translating electric dipole moment.

This is similar to the Mac Gregor theory [16] in so far as the dipole rotates, but Mac Gregor places the positive and negative charges of the dipole symmetrically about the origin. For this reason, the rotation of the dipole cannot produce a $\boldsymbol{B}^{(3)}$ field in Mac Gregor's theory, but can in our theory. The conventional $\boldsymbol{E}^{(1)}$ field of classical vacuum electrodynamics [20] has simply been replaced by $\boldsymbol{\mu}^{(1)}/(\epsilon_0 V)$, which obviously has the same units of V m^{-1} in *S.I.* This innocent replacement allows clarification of the physical origin of the Evans-Vigier field, which becomes recognizable as precisely analogous with the magnetic field produced by a solenoid. It also becomes clear that there is no longitudinal electric field, as deduced elsewhere [1-12], because there is none in a solenoid.

Therefore $\boldsymbol{\mu}^{(1)}$ rotates *with one end fixed*, the other tip traces out a helix as the electromagnetic wave propagates in vacuo. This is the precise physical origin of the Evans-Vigier field, observable experimentally in magneto-optical effects such as the inverse Faraday effect [15]. The interesting concepts of Mac Gregor [16] can therefore be used for $\boldsymbol{B}^{(3)}$ provided that one tip of the rotating dipole is fixed at the origin, which lies on the Z axis of propagation, while the other tip rotates. The mass distribution [16] must be adjusted accordingly so that mass is concentrated at or near the origin, and this is precisely the concept used by de Broglie, Vigier and Bohm [6] in the realist view of quantum mechanics, in which the photon has mass.

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Paper 19

Electromagnetism in Curved Space-time

A suggestion is developed for a theory of electromagnetism in curved space-time, a theory based on a novel *anti*symmetric Ricci tensor which is postulated to be directly proportional to the $G_{\mu\nu}$ tensor of Evans and Vigier, and which therefore deals self-consistently with the experimentally observable $\boldsymbol{B}^{(3)}$ field of magneto-optics.

Key words: Electromagnetism; general relativity; $\boldsymbol{B}^{(3)}$ field.

In this note, a brief summary is given of the essentials of a novel theory [1—3] of electromagnetism, a theory necessitated by the tiny experimental magneto-optic effects [4—8] which need for their self-consistent explanation the $\boldsymbol{B}^{(3)}$ field [9—15] in *curved* space-time. The essence of our argument here is that $\boldsymbol{B}^{(3)}$ can be obtained straightforwardly from the Riemann tensor [6—18] by using the contraction indicated by

$$R^{(A)}_{\mu\nu} := R^{\lambda}_{\lambda\mu\nu} . \tag{2.19.1}$$

This produces an *antisymmetric* Ricci tensor $R^{(A)}_{\mu\nu}$ to which the electromagnetic field tensor $G_{\mu\nu}$ introduced by Evans and Vigier [9,10] is directly proportional,