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MAGNETIZATION OF AN ELECTRON PLASMA BY MICROWAVE PULSES: FARADAY INDUCTION

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It has been argued theoretically that the recently proposed vacuum field $\boldsymbol{B}^{(3)}$ is not accompanied by a real electric field $\boldsymbol{E}^{(3)}$. Experimental evidence for this inference is available in the data reported by Deschamps *et al.* [10], using microwave magnetization of an electron plasma set up in helium gas. Faraday induction due to $\boldsymbol{B}^{(3)}$ does not occur in the inert gas and is not observed experimentally in the absence of free electrons. Whenever $\boldsymbol{B}^{(3)}$ interacts with free electrons, however, Faraday induction occurs through a pulse of induced magnetization (i.e., induced orbital electronic angular momentum).

Key words: $\boldsymbol{B}^{(3)}$ field, Faraday induction.

1. INTRODUCTION

The type of cyclically symmetric, non-Abelian, Lie algebra used to define the novel vacuum field $\boldsymbol{B}^{(3)}$ [1–8] indicates that it is accompanied in the vacuum by an imaginary and unphysical electric field $i\boldsymbol{E}^{(3)}$. The *non*-existence of a real electric field in the defining non-Abelian algebra is indicated simply by considering the elementary property that the cross product of two polar vectors (two electric fields) cannot produce another polar vector (another electric field). It produces an axial vector (a magnetic field). On the other hand, the cross product of two axial vectors (two magnetic fields) can produce another axial vector. In consequence, the magnetic field algebra [1–8] is

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

which is cyclically symmetrical in the indices (1), (2) and (3) of the circular basis. Here "*" denotes as usual "complex conjugate". In this algebra, $\boldsymbol{B}^{(1)}$ and $\boldsymbol{B}^{(2)}$ are the ordinary vacuum plane waves, but $\boldsymbol{B}^{(3)} = \boldsymbol{B}^{(3)*}$ is real and phase free. It is a spin field which propagates at the speed of light through the vacuum and can be detected experimentally through its characteristic square root power density profile ($I_0^{1/2}$) when it magnetizes an electron plasma.

The corresponding algebra [1–8] for electric fields is, on the other hand,

$$\boldsymbol{E}^{(1)} \times \boldsymbol{E}^{(2)} = -E^{(0)}(i\boldsymbol{E}^{(3)})^*, \qquad \boldsymbol{E}^{(2)} \times (i\boldsymbol{E}^{(3)}) = -E^{(0)}\boldsymbol{E}^{(1)*}, \qquad (i\boldsymbol{E}^{(3)}) \times \boldsymbol{E}^{(1)} = -E^{(0)}\boldsymbol{E}^{(2)*}, \tag{2}$$

which is symmetric in $\boldsymbol{E}^{(1)}$, $\boldsymbol{E}^{(2)}$, and $i\boldsymbol{E}^{(3)}$. The algebra shows that $(i\boldsymbol{E}^{(3)})^* = -i\boldsymbol{E}^{(3)}$ is pure imaginary and unphysical, and formally takes the symmetry of an *axial* vector. Such a result is the outcome of special relativity. The vectors $\boldsymbol{E}^{(1)}$ and $\boldsymbol{E}^{(2)}$ (the ordinary plane waves) are mathematically complex quantities (with real and imaginary parts).

In this Letter, O(3) gauge geometry [5, 9] is used to show that there is a formal equation linking $\boldsymbol{B}^{(3)}$ and $i\boldsymbol{E}^{(3)}$ in the vacuum, one which is structurally identical with a Faraday induction equation. In the absence of matter, however, $\boldsymbol{B}^{(3)}$ can never be accompanied by a real $\boldsymbol{E}^{(3)}$, and so no Faraday induction occurs in the vacuum of a real $\boldsymbol{E}^{(3)}$ by $\boldsymbol{B}^{(3)}$ of a pulse of radiation. This inference is supported experimentally by the results of Deschamps *et al.* [10]. These authors observed Faraday induction due to an induced magnetization ($\boldsymbol{M}^{(3)}$) in a plasma, but when the plasma was removed, no induction occurred in the residual inert gas (helium). $\boldsymbol{M}^{(3)}$ is induced by $\boldsymbol{B}^{(3)}$ and is proportional to powers of e, the electronic charge. If there is no plasma there are no free electrons, and in consequence $\boldsymbol{M}^{(3)}$ (the induced orbital electronic angular momentum) is zero for all $\boldsymbol{B}^{(3)}$. Faraday induction occurs [10] due to an $\boldsymbol{M}^{(3)}$ pulse, which sets up an electromotive force and Ohm's law current in a 100 turn induction coil [10] through the Faraday law of induction,

$$\nabla\times \boldsymbol{E}_T = -\mu_0 \frac{\partial \boldsymbol{M}^{(3)}}{\partial t} . \tag{3}$$

Here μ_0 is the vacuum permeability in S.I. units, and $\boldsymbol{E}_T$ is the transverse induced electric field. In the absence of a plasma, this field is zero experimentally [10]. Therefore, the field $\boldsymbol{B}^{(3)}$ does *not* produce induction in the absence of electrons. The reason for this is developed in Sec. 2.

2. ABSENCE OF FARADAY INDUCTION DUE TO A PULSE OF $\boldsymbol{B}^{(3)}$

The existence of $\boldsymbol{B}^{(3)}$ is indicated by the algebra (1) and means that the gauge geometry of vacuum electromagnetism must be extended from the conventional, planar, O(2) to the three-dimensional O(3). If this is carried out self-consistently [5], using the rigorous theory of gauge geometry, the result is that the ordinary vacuum Faraday law equations:

$$\nabla\times \boldsymbol{E}^{(1)} = -\frac{\partial \boldsymbol{B}^{(1)}}{\partial t}, \tag{4a}$$

$$\nabla\times \boldsymbol{E}^{(2)} = -\frac{\partial \boldsymbol{B}^{(2)}}{\partial t}, \tag{4a}$$

are supplemented by an equation which can be written formally as

$$\nabla\times (i\boldsymbol{E}^{(3)}) = -\frac{\partial \boldsymbol{B}^{(3)}}{\partial t} = 0 . \tag{5}$$

Eq. (5) does not exist on O(2) electrodynamics, whereas Eqs. (4) refer as usual to plane waves

$$\begin{aligned} \boldsymbol{E}^{(1)} = \boldsymbol{E}^{(2)*} &= \frac{E^{(0)}}{\sqrt{2}}(\boldsymbol{i} - i\boldsymbol{j})e^{i\phi}, \\ \boldsymbol{B}^{(1)} = \boldsymbol{B}^{(2)*} &= \frac{B^{(0)}}{\sqrt{2}}(i\boldsymbol{i} + \boldsymbol{j})e^{i\phi}, \end{aligned} \tag{6}$$

where ϕ denotes the electromagnetic phase. It can be seen that Eq. (5) formally relates $\boldsymbol{B}^{(3)}$ and $i\boldsymbol{E}^{(3)}$ of Eqs. (1) and (2). This means that $\partial \boldsymbol{B}^{(3)}/\partial t$ can never produce a physical $\boldsymbol{E}^{(3)}$, i.e., Faraday induction due to $\boldsymbol{B}^{(3)}$ cannot occur in the absence of matter. In the presence of free electrons, on the other hand, a $\boldsymbol{B}^{(3)}$ pulse produces a pulse of magnetization, $\boldsymbol{M}^{(3)}$, which results in an $\boldsymbol{E}_T$ pulse through Eq. (3).

3. ANALYSIS OF EQUATION (5)

Equation (5) means that a hypothetically non-zero $\partial \boldsymbol{B}^{(3)}/\partial t$ (e.g., postulated to exist in a pulse of microwave radiation lasting a microsecond [10]) formally produces the curl of an imaginary electric field $i\boldsymbol{E}^{(3)}$ in *the same* longitudinal polarization, (3). Therefore, a pulse of $\boldsymbol{B}^{(3)}$ in the vacuum cannot produce a transverse electric field; the latter is produced as usual by a transverse magnetic field as described in the ordinary Eqs. (4a) and (4b) of vacuum electromagnetism. On the other hand, a pulse of longitudinal magnetization, $\boldsymbol{M}^{(3)}$, produces a transverse $\boldsymbol{E}_T$ as in Eq. (3), an $\boldsymbol{E}_T$ that is picked up [10] by the induction coil. Evidently, $\boldsymbol{E}_T$ is not a plane wave propagating at the speed of light.

The physical (i.e., real) part of Eq. (5) is

$$\frac{\partial \boldsymbol{B}^{(3)}}{\partial t} = 0, \tag{7}$$

which must be interpreted to mean that $\partial \boldsymbol{B}^{(3)}/\partial t$ in tesla per second cannot produce the curl of a physically meaningful electric field strength. Such a field would have to be *perpendicular* to $\boldsymbol{B}^{(3)}$, but these fields are transverse plane *waves* in axes (1) and (2).

4. DISCUSSION

The $\boldsymbol{B}^{(3)}$ field from Eqs. (1) is real and physical and is formed in electromagnetic radiation propagating at the speed of light. It is proportional [1–8] to the angular momentum of the classical field, an angular momentum in the (3) axis which is relativistically invariant. In the quantized field this becomes the Dirac constant $\hbar$ for each photon, a universal, unchanging property. If we consider in a thought experiment a beam of radiation of a given cross section to contain only one photon, then the $B^{(0)}$ of that photon is also fixed, being the scalar amplitude per photon of the magnetic flux density carried by the beam. In the quantum field theory it is not possible for one photon to carry less or more inductance. Thus $\boldsymbol{B}^{(3)}$ per photon, being $B^{(0)}$ per photon multiplied by a unit vector $e^{(3)}$, cannot be changed in time for a given beam cross section. If now another photon is added to the beam, a similar situation holds; we have $2B^{(3)}$, which cannot be changed with time. This argument extends to all photons of the beam, leading to $\partial B^{(3)}/\partial t = 0$, as in Eq. (7). It is always possible to change the beam cross section, by focusing, in which case $\nabla B^{(0)}$ is not zero. In this eventuality, however, we must consider the convective derivative [11],

$$\frac{dB^{(0)}}{dt} := \frac{\partial B^{(0)}}{\partial t} + \boldsymbol{v} \cdot \nabla B^{(0)}, \tag{8}$$

where $\boldsymbol{v}$ is the linear velocity in axis (3) of the $\boldsymbol{B}^{(3)}$ field, the velocity of light. The Faraday law of induction then takes the integral form given by Jackson [11], for example,

$$\frac{d}{dt}\int_S \boldsymbol{B}^{(3)} \cdot \boldsymbol{n}da = \int_S \frac{\partial \boldsymbol{B}^{(3)}}{\partial t} \cdot \boldsymbol{n}da + \oint_C \boldsymbol{B}^{(3)} \times \boldsymbol{v} \cdot d\boldsymbol{l}, \tag{9}$$

and since $\boldsymbol{B}^{(3)}$ is parallel to $\boldsymbol{v}$ the second term on the right hand side disappears. We have argued that the intrinsic $\partial \boldsymbol{B}^{(3)}/\partial t$ is zero, and so again there is no Faraday induction by $\boldsymbol{B}^{(3)}$ in the vacuum.

Whenever $\boldsymbol{B}^{(3)}$ produces $\boldsymbol{M}^{(3)}$ in free electrons, however, there is induction, because $\boldsymbol{M}^{(3)}$ is proportional to induced electronic orbital angular momentum, which is a circulating current of electrons, classically with no linear momentum. This pulse of current produces Faraday induction in another coil. Clearly, $\boldsymbol{M}^{(3)}$ has no classical linear momentum relative to the induction coil, whereas $\boldsymbol{B}^{(3)}$ is travelling at the speed of light with respect to it.

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