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REPLY TO A. LAKHTAKIA: EXPERIMENTAL MEASUREMENT OF $\boldsymbol{B}^{(3)}$

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In answer to the assertion by Lakhtakia [1] that $\boldsymbol{B}^{(3)}$ is *unknowable*, presumably unmeasurable, the experimental conditions for its measurement are defined.

Key words: spin field $\boldsymbol{B}^{(3)}$, magnetization, plasma.

1. INTRODUCTION

The defining algebra for the vacuum field $\boldsymbol{B}^{(3)}$ has been discussed in detail [2-10], and is

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

where $\boldsymbol{B}^{(1)}$ and $\boldsymbol{B}^{(2)}$ are plane waves, and where $B^{(0)}$ is the scalar magnitude of the magnetic flux density of an electromagnetic beam propagating in the 3 axis through the vacuum. Equation (1) is written in a circular basis [2-10], (1), (2), (3) and $\boldsymbol{B}^{(3)}$ is a real and physical magnetic flux density which is defined by the well known conjugate product $\boldsymbol{B}^{(1)} \times \boldsymbol{B}^{(2)}$. Thus, if $\boldsymbol{B}^{(3)}$ is *unknowable* as asserted by Lakhtakia [1], then so is the conjugate product. The latter, however, is the fundamental entity of magneto-optics, and is reviewed in Ref. [6] by Zawodny. The term *unknowable* is irregular, but presumably means *unmeasurable*. If Lakhtakia is indeed asserting that $\boldsymbol{B}^{(1)} \times \boldsymbol{B}^{(2)}$ is unmeasurable, he is contradicted by experience, for example the inverse Faraday effect

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[11], light shifts [12], and the optical Faraday effect [13]. Significantly, Lakhtakia [1] refers to none of these phenomena, well known for some thirty three years.

2. EXPERIMENTAL MEASUREMENT OF $\boldsymbol{B}^{(3)}$

By solving the classical, but relativistic, Hamilton-Jacobi equation of one electron, e, in the electromagnetic field, A_μ, it can be shown [5, 14] using, for the most part, standard methods of solution [15] that there exists a characteristic *square root* power density dependence (denoted $I_0^{1/2}$) of the magnetization, $\boldsymbol{M}^{(3)}$, set up by $\boldsymbol{B}^{(3)}$ in a plasma of N non-interacting electrons. This is measurable experimentally by a straightforward modification of the well known demonstration of the inverse Faraday effect by Deschamps *et al.* [16], twenty four years ago. An $I_0^{1/2}$ dependence of $\boldsymbol{M}^{(3)}$ is not obtainable at first order from the plane waves $\boldsymbol{B}^{(1)}$ and $\boldsymbol{B}^{(2)}$ because at first order in $B^{(0)}$ it would average to zero. At second order in $B^{(0)}$ (first order in I_0) magnetization is produced as in the conventional interpretation [2–10] of the inverse Faraday effect. The condition for the observation of the $I_0^{1/2}$ dependence of $\boldsymbol{M}^{(3)}$ is [5, 14]

$$\omega \leq \frac{e}{m} B^{(0)}, \tag{2}$$

where ω is the angular frequency of the electromagnetic beam (for example the 30 GHz microwave frequency of Deschamps *et al.* [16]), and e/m is the charge to mass ratio of the electron, i.e., about 2×10^{11} C kgm^{-1}. In condition (2), it is straightforward to show [5, 14] that

$$|\boldsymbol{M}^{(3)}| \sim -\frac{Ne^2}{2m\omega^2}\left(\frac{c}{\epsilon_0}\right)^{\frac{1}{2}} I_0^{\frac{1}{2}}, \tag{3}$$

where ϵ_0 is the permittivity of the vacuum in S.I. units, c the speed of light in the vacuum, and N the number of non-interacting electrons. In terms of $\boldsymbol{B}^{(3)}$ the magnetization under condition (2) is given by

$$\boldsymbol{M}^{(3)} \sim -\frac{Ne^2c^2}{2m\omega^2}\boldsymbol{B}^{(3)}, \tag{4}$$

and is to order *one-half* in the beam power density I_0 (W m^{-2}).)

Measurement of $|\boldsymbol{M}^{(3)}|$ as a function of $I_0^{1/2}$ therefore proves unequivocally the presence of $\boldsymbol{B}^{(3)}$ in the vacuum, with several fundamental consequences in the theory of fields and particles [2–10].

3. EXPERIMENTAL DETAILS

These have been discussed elsewhere [14], but are reproduced here in summary. Deschamps *et al.* [16] have demonstrated experimentally the phenomenon of magnetization by microwave pulses of an electron plasma set up in helium gas by pulses of megawatt peak power. The microwave pulses were detected through Faraday induction in a 100 turn induction coil by a synchronized oscilloscope. The plasma was produced in a pyrex tube filled with helium gas, a tube 0.065 m in diameter and 0.2 m in length. The area of the sample was therefore about 0.003 m^2. For a peak microwave power of 1.0 MW the peak power density was therefore about 3 x 10^8 W m^{-2}, producing a peak $\boldsymbol{B}^{(3)}$ from the equation [2–10]

$$\boldsymbol{B}^{(3)} = B^{(0)}\boldsymbol{e}^{(3)} = \left(\frac{I_0}{\epsilon_0 c^3}\right)^{\frac{1}{2}}\boldsymbol{e}^{(3)} \tag{5}$$

of about 0.002 T. The 30 GHz frequency used by Deschamps *et al.* was about 2 x 10^{10} rad s^{-1}, so under their reported [16] experimental conditions

$$\omega \sim 50\frac{e}{m}B^{(0)}. \tag{6}$$

In consequence, the Hamilton-Jacobi equation of e in A_μ shows that the magnetization $\boldsymbol{M}^{(3)}$ will be dominated by an I_0 dependence under condition (6). Specifically [5, 14],

$$|\mathbf{M}^{(3)}| \sim -\frac{Ne^3}{2m^2\omega^3\epsilon_0 c} I_0 . \tag{7}$$

In terms of $\mathbf{B}^{(3)}$,

$$\mathbf{M}^{(3)} \sim -\frac{Ne^3c^2}{2m^2\omega^3} B^{(0)}\mathbf{B}^{(3)} , \tag{8}$$

which is a result of classical special relativity applied to the orbital angular momentum of e in A_μ. The expected I_0 dependence of $|\mathbf{M}^{(3)}|$ from Eq. (7) was observed and reported in Fig. (2) of Ref. [16a].

This is alone sufficient to show, by reference to Eq. (8), that $\mathbf{B}^{(3)}$ *is an experimental obervable*, but to isolate the $I_0^{1/2}$ profile of Eq. (3) unequivocally and definitively through experiment, condition (2) must be satisfied experimentally by increasing $B^{(0)}$ for constant ω. This can be done by increasing the peak power density, by shortening the pulse time and decreasing the sample area (the area of the pyrex tube). With contemporary detection technology, e.g. oscilloscopes that can detect nanosecond pulses and shorter, the detection of the expected $I_0^{1/2}$ profile should be straight forward.

4. DISCUSSION

The theory of $\mathbf{B}^{(3)}$ has been developed extensively in Refs. [2–10], and it is clear that it is a new vacuum field, the field fundamentally responsible for *all* magneto-optic phenomena [6]. We have discussed the precise experimental conditions under which its characteristic $I_0^{1/2}$ profile dominates, because such a profile cannot be obtained from the plane waves $\mathbf{B}^{(1)}$ and $\mathbf{B}^{(2)}$ at first order in $B^{(0)}$. It can *only* be obtained from $\mathbf{B}^{(3)}$, and serves therefore to filter out the specific effects of $\mathbf{B}^{(3)}$ from any putative first order effects of $\mathbf{B}^{(1)}$ and $\mathbf{B}^{(2)}$. These three physical vacuum fields are cyclically related by Eq. (1) in such a way that the existence of any one means the existence of the other two [2–10].

Lakhtakia [1] has chosen to assert the non-measurability of $\mathbf{B}^{(3)}$. This assertion is unscientific, however, because it is made without scholarly reference to well known phenomena, such as the inverse Faraday effect [11], phenomena which can be interpreted [2–10] in terms of the conjugate product $\boldsymbol{B}^{(1)} \times \boldsymbol{B}^{(2)}$. The latter is therefore an experimental observable, and is algebraically equal to $iB^{(0)}\boldsymbol{B}^{(3)*}$. Therefore $\boldsymbol{B}^{(3)}$ is an experimental observable, as discussed extensively in the recent literature [2–10]. Lakhtakia [1] has incorrectly asserted that the longitudinal $\boldsymbol{E}^{(3)}$ is real, whereas it is shown repeatedly in the literature [2-10] that it is unphysical, and represented by the *pure imaginary* $i\boldsymbol{E}^{(3)}$. This is a direct result of the defining algebra of $i\boldsymbol{E}^{(3)}$ [2–10],

$$\boldsymbol{E}^{(1)} \times \boldsymbol{E}^{(2)} = -E^{(0)}(i\boldsymbol{E}^{(3)})^{*}, \text{ et cyclicum} \tag{9}$$

which is cyclically symmetric in $\boldsymbol{E}^{(1)}$, $\boldsymbol{E}^{(2)}$ and $i\boldsymbol{E}^{(3)}$. No physical effects at first order are expected from $i\boldsymbol{E}^{(3)}$, and none have been observed.

One of the most profoundly important consequences of $\boldsymbol{B}^{(3)}$ is that the photon, in the quantized field theory, carries mass, because $\boldsymbol{B}^{(3)}$ is a longitudinal polarization prohibited by special relativity in a boson without mass. Several other consequences of $\boldsymbol{B}^{(3)}$ are developed in detail elsewhere [2–10].

Lakhtakia [1] refers to a paper by Santamato *et al.* [17] in support of the assertion [1] that $\boldsymbol{B}^{(3)}$ is *unknowable*. The work by Santamato *et al.* [17] reports the induction by a laser of collective precession of molecules in an aligned nematic film. The induction of magnetization by a magnetic field such as $\boldsymbol{B}^{(3)}$ involves the transfer of *orbital* angular momentum, but the effect reported by Santamato *et al.* [17] is the well known ability of circularly polarized radiation to transfer *mechanical* angular momentum to material matter. Such an effect was first reported by Beth [18] and is a well known textbook phenomenon, mentioned, for example by Atkins [19].

Finally, Lakhtakia [1] refers to papers by Grimes [20] and himself [21] and claims that there is confusion in the work of Evans and others [2-10] between *complex valued phasors and real fields*. Essentially, in conflict with experience, these papers appear to assert that the well known conjugate product is unmeasurable. This assertion is best answered by recourse to the defining algebra (1), in which the phasors $\boldsymbol{B}^{(1)}$ and $\boldsymbol{B}^{(2)}$ form the observable $iB^{(0)}\boldsymbol{B}^{(3)*}$ through a cross product, the ordinary conjugate product of magneto-optics [5].

Summary

Lakhtakia [1] asserts that $\boldsymbol{B}^{(3)}$ is *unknowable*. Theoretically, $\boldsymbol{B}^{(3)}$ is a direct result of the defining algebra (1) of this paper. The experimental measurement of $\boldsymbol{B}^{(3)}$ was discussed and is summarized in relation to Lakhtakia's questions:

1. The uniform magnetic field $\boldsymbol{B}^{(3)}$ is measurable through its characteristic $I_0^{1/2}$ profile.
2. $\boldsymbol{B}^{(3)}$ is understood to act at second order in $B^{(0)}$ in several *experimentally* established magneto-optic phenomena such as the inverse and optical Faraday effects and light shifts in atomic spectra. The well known conjugate product is expressible now as $iB^{(0)}\boldsymbol{B}^{(3)}$, another experimental observable.
3. $i\boldsymbol{E}^{(3)}$ is *unphysical* and for this reason is not experimentally observable. It is a pure imaginary quantity.

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NOTE

Although the present author viewed [20] and [21] as papers which raised objections to the spin field $\boldsymbol{B}^{(3)}$ and which therefore deserved a scientific reply, *Physica B* did not give him the right of reply.