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REPLY TO CRITICISMS OF THE $\boldsymbol{B}^{(3)}$ FIELD

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The confusion and self-contradiction among recent critics of the $\boldsymbol{B}^{(3)}$ (Evans-Vigier) field are analysed. Barron [17] and Buckingham [18] assert that the field is zero by symmetry. Grimes [21] asserts that the field is *non*-zero but *fortuitous*. Lakhtakia in one paper [19] asserts that $\boldsymbol{B}^{(3)}$ is *non*-zero but *not fundamental*, and in a second paper that it is *unknowable* and therefore may as well be zero. A rebuttal is given of each the individual papers, and it is shown that the Evans-Vigier field is the fundamental magnetizing field of electromagnetic radiation.

Key words: $\boldsymbol{B}^{(3)}$ field, reply to criticisms.

1. INTRODUCTION

In recent months it has been argued in detail [1–12] that there exists in the vacuum a phase-free magnetic flux density $\boldsymbol{B}^{(3)}$, the Evans-Vigier field, which is the fundamental magnetizing field of electromagnetic radiation. The correctly relativistic classical theory [7] shows that the magnetization of an electron plasma due to $\boldsymbol{B}^{(3)}$ is proportional, under the right conditions, to the square root of the power density I_0 (W m^{-2}) of microwave radiation, and an experiment is being planned [13] to test the theory. There are by now many ways in which $\boldsymbol{B}^{(3)}$ can be expressed within

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field theory, and its self-consistency has been demonstrated repeatedly in a series of papers [8–12]. The theory has been developed by Roy [14] in cosmology, by Evans and Vigier [7], and by Evans, Jeffers and Roy [15]. The experimental test of the theory is planned by a group of experimentalists and theoreticians [16].

In this paper a detailed rebuttal of some early criticisms of $\boldsymbol{B}^{(3)}$ is given with a view to persuasion rather than sterile polemic. The answers in this paper are directed at two groups of critics, that of Barron [17] and Buckingham [18] and that of Lakhtakia [19,20] and Grimes [21].

In Sec. 1, consideration is given to the claims made by Barron [17] and Buckingham [18], working in cooperation with the former author, that the Evans-Vigier field is zero by symmetry. It is shown that these arguments are incorrect.

In Sec. 2, consideration is given to two critical papers by Lakhtakia [19,20] and one by Grimes [21], working in cooperation with the former author. The arguments by Lakhatkia are shown to be confused and self-contradictory. Grimes [21] concludes that the Evans-Vigier field is *non*-zero and therefore exists in vacuum, is a magnetic field, but is somehow not fundamental. This conclusion is clear in only one respect: It contradicts diametrically that of Barron [17] and of Buckingham [18]. Lakhtakia in one paper [19] appears to endorse Grimes' conclusion, because the two papers are marked parts 1 and 2 (Lakhtakia and Grimes, respectively) but in a second paper [20] asserts that the Evans-Vigier field is *unknowable*. Lakhtakia's first paper [19] contradicts his second [20], and his second [20] contradicts the paper by Grimes [21]. Lakhtakia therefore appears neatly to destroy both his own credibility and by implication that of Grimes. Nevertheless a detailed rebuttal is given in this section. The present author finds some parts of these critical polemics to be obscure but will attempt to shed light on the matter.

It is concluded that that these polemics are confused and in several places contain elementary errors. Lakhtakia in particular uses unscientific terminology and omits scholarly reference to previous work in magneto-optics, some of it well-known experimental work available in textbooks. An attempt is made in this paper to point out these errors and scholarly omissions as simply and clearly as possible.

2. SYMMETRY ARGUMENTS

It has been argued by Barron [17] that the Evans-Vigier field is zero by charge-conjugation symmetry. This argument has been answered in detail [1–12], and we restrict our discussion here to our previous concluding remarks, i.e., that the field $\boldsymbol{B}^{(3)}$ is defined by a set of cyclic relations between magnetic field components in vacuo which conserves $\hat{C}$ symmetry. The incorrect nature of Barron's argument (based on arbitrary diagrammatic constructs) has been pointed out by Evans [3], Vigier [22], Evans and Vigier [7], and Huang [23].

Buckingham, in voluminous correspondence with the present author, has asserted that the Evans-Vigier field is zero on the following grounds, taken from a recent review by Buckingham [18] of Ref. 6. (This appears to be the only published account of Buckingham's views.) In this review of a book edited by Evans and Kielich [6], Buckingham writes:

> Evans proposes that a circularly polarized beam is associated with a static magnetic field in the direction of propagation and that this field is of opposite sign for right and left circular polarization. However such a proposal requires that rotating positive or negative charges radiate circularly polarized light having opposite magnetic fields; that is, there would be two distinct types of right (and left) circularly polarized light, contrary to experience. The paper contains lengthy and probably unrefereed criticisms of L. D. Barron's comments on a related paper by Evans and is seriously out of place in this volume [6].

To this author, positive scientific criticism is never out of place, Buckingham is evidently indulging in negative criticism, in that his conclusion is simply that $\boldsymbol{B}^{(3)}$ is zero, but does not have the monopoly of wisdom: science thrives on the opportunity to reply. These vague comments by Buckingham have been answered fully elsewhere [6–8], they amount to a discussion of the sign of $B^{(0)}$, the scalar magnetic flux density amplitude of electromagnetic radiation in vacuum. The reply to Buckingham is that it is the *absolute magnitude* of $B^{(0)}$ that enters into the classical theory of electrodynamics [24] and into quantum electrodynamics [25]. The direction of Maxwell's rotating field is given in a book such as that by Jackson [24]. Its direction is fixed by the positive absolute magnitude of $B^{(0)}$ (or of $E^{(0)} = cB^{(0)}$) and is outward from the origin. The radiating

entity is an *electron* current at infinity. To apply Buckingham's argument, one would have to consider a radiating *positron* at infinity, thus changing the subject from electrodynamics to *positrodynamics*. Similarly, quantum electrodynamics is based on the existence *only* of electrons and photons. Buckingham's views are simply an attempt to bolster the erroneous $\hat{C}$ symmetry argument of Barron [17].

The fallacy of Buckingham's assertion is seen mathematically in the correctly relativistic description of magnetization by $\boldsymbol{B}^{(3)}$ of a simple N-electron plasma, Eq. (405) of Ref. 7, Vol. 1,

$$\boldsymbol{M}^{(3)} = -\frac{Ne}{2m_0} \cdot \frac{e^2c^2}{\omega^2} \left(\frac{B^{(0)}}{\left(m_0^2\omega^2 + e^2B^{(0)2}\right)^{1/2}} \right) \boldsymbol{B}^{(3)}. \tag{1}$$

Here e/m_0 is the charge to mass ratio of the electron and ω the angular frequency of circularly polarized radiation interacting with the electron. Since $\boldsymbol{B}^{(3)} = B^{(0)}\boldsymbol{e}^{(3)}$, Eq. (1) shows that if, for the sake of argument, we go through the purely mathematical exercise of changing the sign of $B^{(0)}$, the sign of $\boldsymbol{M}^{(3)}$ is *not* changed. In other words it is the absolute magnitude of $B^{(0)}$ that enters into the theory and definition [1–12] of observable magnetization by $\boldsymbol{B}^{(3)}$. In textbooks on classical electrodynamics, including a book by Barron [26], the sign of $B^{(0)}$ is not discussed, and currents are expressed in units of the charge on the electron, not in units of charge on the positron.

In the condition

$$\omega < \frac{e}{m_0} B^{(0)}, \tag{2}$$

Equation (1) reduces through straightforward algebra to

$$\boldsymbol{M}^{(3)} \underset{\omega \to 0}{\to} -\frac{N}{2} \cdot \frac{e^2c^2}{2m_0\omega^2} \boldsymbol{B}^{(3)}, \tag{3}$$

showing that, under this condition, $\boldsymbol{M}^{(3)}$ is proportional to the *square root* of the beam power density I. Clearly, if $\boldsymbol{B}^{(3)}$ were zero, as asserted by Barron [17] or by Buckingham [18], there would be no magnetization, i.e., no inverse Faraday effect in contradiction with experience [27].

Therefore, both these authors have erred in an elementary manner and are not immune from replies to their criticism.

3. CRITICISM BY LAKHTAKIA [19,20] AND GRIMES [21]

These authors, working in cooperation, have produced two papers apparently attempting to criticize the Evans-Vigier field; these papers are marked parts one and two and originate from the same University. The approach used in this section is to reply to each part in detail. It is important to note that these authors reach diametrically the *opposite* conclusion to that of the critics in Sec. 1, i.e., conclude that the Evans-Vigier field is *non-zero*, but assert that it is not fundamental. Lakhtakia's often obscure points of view are answered as follows.

(a) He claims that frequency is a mathematical artifact, whereas frequency is to this author an experimental observable, as in the caesium clock.

(b) He first claims that a complex phasor is unobservable, then claims that its real part is after all observable. In texts such as that of Jackson [24] or de Broglie [28], both the real and imaginary parts of the phasor are used routinely in the complete solution of Maxwell's equations in vacuo. This is also the case in the vast majority of texts known to this author. The text by de Broglie [28], for example, discusses the physical importance of the imaginary part of the phasor [29].

(c) The conjugate product is given in Lakhtakia's Eq. (7), and we are told that it is a frequency domain quantity. It is well known in non-linear optics, however [6,30], that the conjugate product is *phase free* and proportional to the antisymmetric part of the intensity tensor.

(d) There follows an entirely obscure sentence in which we are told that *it is not obvious what one should do about creating a time-domain analogue of the conjugate product.* In reality, the conjugate product is phase free and remains so both in the frequency and time domains.

(e) After his Eq. (11), we are told that the conjugate product is not observable because its real part is zero. This is an elementary error; the conjugate product is the basis of the inverse Faraday effect at second order, as described originally by Piekara and Kielich [31] and by Pershan [32], and by now in several textbooks [33,34] and reviews [35]. Lakhtakia refers to none of this work, and in his second critical paper [20] continues to ignore this source literature. His views are therefore subjective. It is well known [32] that the imaginary conjugate product multiplies the imaginary part of material hyperpolarisability to produce a real and experimentally observable magnetization

[27] in liquids, glasses and electron plasma. The observed magnetization is free of the phase of the electromagnetic field, thus contradicting Lakhtakia experimentally.

(f) We are then told that the magnitude of the Evans-Vigier field is *not arbitrary*, as if Evans and Vigier claim that it *is* arbitrary. The obscurity is further compounded by the assertion that $\boldsymbol{B}^{(3)}$ does not depend on the polarization state, whereas in the source literature [1–12] it is clearly explained that $\boldsymbol{B}^{(3)}$ changes sign with circular polarization and therefore vanishes in linear polarization.

(g) There follows a passage which to this author is incomprehensible. We are being told, apparently, that the directions of the conjugate product and of the Evans-Vigier field are the same for an elliptically polarized plane wave, which is true, but then it is asserted that the connection between $\boldsymbol{B}^{(3)}$ and linearly polarized plane waves has been *eliminated*. In reality $\boldsymbol{B}^{(3)}$ exists [17] in both circular and elliptical polarization and vanishes in linear polarization, because linear polarization is 50% right and 50% left circular polarization.

(h) Lakhtakia then appears to claim that $\boldsymbol{B}^{(3)}$ is not a solution of Maxwell's equations by a play on words in the present author's previous work [1,6]. However, $\boldsymbol{B}^{(3)}$ is a solution of Maxwell's vacuum equations and is, inter alia, a magnetic flux density in vacuo [7,24]. If Lakhtakia is indeed asserting this, and his wording is very obscure, then he contradicts his own conclusion in this paper that the $\boldsymbol{B}^{(3)}$ field is non-zero. If so, it must be a magnetic field and thus a solution of Maxwell's equations in vacuo.

(i) Finally, we are told that the present author's relation of $\boldsymbol{B}^{(3)}$ to the Stokes parameter s_3 [1,6] is a *contrivance*. The reason for this vague assertion is not given, and we have no hope here of fathoming this point of view.

All of this is a sterile polemic because it contains elementary factual errors and ignores the source literature in an unscholarly manner. Its conclusion appears to be that $\boldsymbol{B}^{(3)}$ is *non-zero* but somehow not fundamental. In reality, $\boldsymbol{B}^{(3)}$ is the fundamental magnetizing field of electromagnetic radiation, because, if it were not, there would be no magneto-optics and Hamilton's principle of least action would be incorrect. Thus $\boldsymbol{B}^{(3)}$ is fundamental enough to this author.

In a second paper, Lakhtakia contradicts his own

conclusion [19], cited already, and asserts that $\boldsymbol{B}^{(3)}$ is *unknowable* and *ghastly* and so might as well be zero. The present author does not doubt that to Lakhtakia, this is the case, but the present author's concern is with the description of nature. A detailed rebuttal of Lakhtakia's second paper [20] is already available in the literature [12,20]. We have been concerned here with a detailed rebuttal of his first paper.

The paper labelled *part two* and authored by Grimes [21] is perhaps a little less obscure, but large parts of it are devoted to a description of standard texbook material from sources such as Panofsky and Phillips [36]. Its conclusion is however that $\boldsymbol{B}^{(3)}$ is *non*-zero but that it is an average value of *a quantity that cycles at twice the field frequency*. Grimes claims that $\boldsymbol{B}^{(3)}$ *may be an useful artifice to calculate angular momentum in a photon field*, but asserts that *there is no static field, and its usefulness is more fortuitous than fundamental*. It appears to be claimed that, since $\boldsymbol{B}^{(3)}$ is non-zero only on average, it cannot be a boson operator in quantum mechanics.

We approach this paper by first pointing out an elementary inconsistency and by then examining the core of its logic, Grimes' Eq. (9), in which the conjugate product is expressed classically in terms of arbitrarily introduced phase parameters labelled α and β.

The inconsistency appears when Grimes claims that the integral of the Evans-Vigier field *across the beam* is the rate at which angular momentum is carried by the beam. The integral of $\boldsymbol{B}^{(3)}$ across the beam is the magnetic flux in webers (Wb), i.e., T m^2; or J s C^{-1}; or J A^{-1} in S.I. units. The rate of change of angular momentum, however, is the torque, which is not a magnetic flux in Wb. This kind of elementary error reduces confidence in the paper. The unit of angular momentum is the unit of action, which is J s, while torque has the unit of work N m or J. However, weber is J s C^{-1}, so there is a current term (A = C s^{-1}) missing completely in Grimes' analysis. The missing current term is $\hat{C}$ negative and is needed to convert $\hat{C}$ positive angular momentum to $\hat{C}$ negative magnetic flux. The correct relation between angular momentum and the Evans-Vigier field is available in the literature [7]. The correct, and manifestly self-consistent, relation between the Evans-Vigier field and electromagnetic torque in vacuo has been established elsewhere [11]. In S.I. units the electromagnetic torque density in vacuo is the conjugate product divided by the permeability in vacuo μ_0.

Leaving this fundamental error aside, we note that the core of the logic in Grimes [21] is his Eq. (9), which asserts essentially that the conjugate product is proportional to $\cos^2(\omega t)$. The basis of this is the assertion that *no product of an imaginary (or virtual [21]) field has actual significance*. Essentially, therefore, if $\boldsymbol{B}^{(1)} = \boldsymbol{B}^{(2)*}$ is the magnetic part of the vacuum plane wave, where * denotes *complex conjugate*, Grimes [21] asserts that $\boldsymbol{B}^{(1)} \times \boldsymbol{B}^{(2)}$ or $\boldsymbol{B}^{(1)} \cdot \boldsymbol{B}^{(2)}$ has no *actual*, presumably physical, significance. This is untenable, however, because the electromagnetic energy (J) is well known to define the fundamental photon $\hbar\omega$ through the electromagnetic energy density (J m^{-3}),

$$En_V = \frac{1}{\mu_0} \boldsymbol{B}^{(1)} \cdot \boldsymbol{B}^{(2)}, \tag{4}$$

and the electromagnetic torque density (J m^{-3}) is,

$$Tq_V = -\frac{1}{\mu_0} \boldsymbol{B}^{(1)} \times \boldsymbol{B}^{(2)}. \tag{5}$$

Neither of expressions (4) or (5) is frequency dependent on the right-hand side. The volume integral

$$\hbar\omega = \int En_V dV \tag{6}$$

is well known, furthermore, to define the *photon itself*, and the photon has no $\cos^2 \omega t$ term in its definition. The logic of Grimes' paper is fundamentally flawed. The photon $\hbar\omega$ i.e., the quantum of electromagnetic energy, is not an average over anything, and so neither is the quantum of electromagnetic torque, which is related to the photon through

$$\hbar\omega \boldsymbol{e}^{(3)} = \int Tq_V dV. \tag{7}$$

Thus $\boldsymbol{B}^{(3)}$ does not cycle from zero to twice the field frequency as asserted by Grimes, and is phase free. Its quantum mechanical equivalent is a boson operator proportional directly to an angular momentum operator and, within a factor $\hbar$, to a group generator [7,8] of O(3).

Similarly, a text such as that of Panofsky and Phillips [36] clearly shows that the volume integral over the Poynting vector can be interpreted as the photon linear momentum (p. 379). The linear momentum density of electromagnetic

radiation is $(\boldsymbol{E}^{(1)} \times \boldsymbol{B}^{(2)})/(\mu_0 c^2)$ in S.I. units and for one photon in the quantum theory is not an average over anything, there being only one photon. Clearly, the photon linear momentum $\hbar\boldsymbol{\kappa}$ does not cycle from zero to twice the field frequency, neither does the photon angular momentum $\hbar$, and neither does the boson operator whose expectation value [6–8] is $\boldsymbol{B}^{(3)}$. The fallacy in Grimes' argument can therefore be seen clearly when we consider a monochromatic beam of radiation consisting of one photon. In this limit there is nothing to average over.

4. SUMMARY

Some attempted criticisms of the Evans-Vigier field have been examined logically and found to contain several errors. The author has collected in this paper the various arguments which rebut these criticisms in their entirety.

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authors have never attempted to communicate with me directly. Lakhtakia proceeded in the same manner when he submitted to *Foundations of Physics Letters* his second paper attacking the work of the present author. The editor of the latter kindly sent a copy of this paper for comment and a possible formal reply in the accepted scientific tradition. Lakhtakia has again abstained from communicating directly with the present author.

This episode constitutes a sad comment on the state of freedom of expression in scientific thought.

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