Reply to the comment on the existence of NRBI media

1998 J. Phys. A: Math. Gen. 31 1111

(http://iopscience.iop.org/0305-4470/31/3/022)

J. Phys. A: Math. Gen. **31** (1998) 1111–1112. Printed in the UK PII: S0305-4470(98)84588-5

COMMENT

Reply to the comment on the existence of NRBI media

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Received 22 May 1997

Abstract. We reply to the recent comment by Weiglhofer and Lakhtakia on the existence of NRBI media.

A comment in this journal [1] by Weiglhofer and Lakhtakia (hereafter referred to as W and L respectively) claims to show that the main points of our paper [2] (denoted RS) concerning the existence of linear non-reciprocal bi-isotropic (NRBI) media are 'either incorrect or inconsequential to modern electromagnetic theory'. RS cites papers by W and/or L which claim that Maxwell's equations forbid the existence of NRBI media. This claim was challenged in RS on the grounds that the veto is a consequence, not of electromagnetism, but of time-reversal considerations applied to an isotropic medium, as explained by Van Vleck and later by Buckingham *et al* (these references appear in [2]). With this background we now reply to the WL comment.

Reply 1. In [3] W gives constitutive relations for $\boldsymbol{B}$ and $\boldsymbol{H}$ for a homogeneous bi-isotropic medium in the $\mathbf{E}$ and $\boldsymbol{B}$ fields of a plane monochromatic wave. These relations contain the 'non-reciprocity parameter α', which is real, and the imaginary 'chirality parameter β' (see L and W in [4]), both macroscopic quantities. W's relation for $\boldsymbol{D}$ in [3] is

$$\boldsymbol{D}(\boldsymbol{x}, \omega) = \epsilon(\omega)\boldsymbol{E}(\boldsymbol{x}, \omega) + (\alpha(\omega) + \beta(\omega))\boldsymbol{B}(\boldsymbol{x}, \omega).$$

Since $\boldsymbol{B}$ is time-odd and $\boldsymbol{D}$ is time-even [2], α is time-odd. (See our equivalent classification in (7) in RS.) The Van Vleck proof requires $\alpha = 0$. Thus, the subsequent discussion by W in [3], which claims to show, on the basis of a so-called 'principle of parsimony', that Maxwell's equations veto the existence of NRBI media, is made irrelevant. A similar argument applies to the claim by L and W in [4] that a covariance constraint due to Post, that arises from Maxwell's equations, imposes the same veto on NRBI media. In (1) of [4] L and W assumed the existence of the non-reciprocity parameter for an isotropic medium and then claimed to show that the Post constraint (PC) requires it to be zero. Because of Van Vleck's proof, this parameter is necessarily zero before the PC is even applied to it.

Reply 2. In [1] W and L stated that 'RS advances two major theses: (1) the PC does not emerge from the structure of modern electromagnetics, but is a symmetry constraint instead'. Nowhere in RS do we state or imply that the PC is not derived from electromagnetic theory. The above statement by W and L does not correctly represent our one main conclusion in [2], namely: whereas W and L claimed that it was Maxwell's equations, as a consequence

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of the PC or the 'principle of parsimony', that require α to vanish, the correct explanation is to be found in the proof by Van Vleck, extended by Buckingham *et al*, that all time-odd property tensors, including α, vanish for an isotropic system. That being so, α should not even appear in the constitutive relations for an isotropic medium.

Reply 3. In [1] W and L stated 'First, let us emphatically state that time-independent (i.e. uniform) electric and magnetic fields do not exist.' First, a time-independent field is not necessarily uniform. Secondly, static field effects (e.g. Pockels, Faraday, converse piezoelectric) have been observed and theories proposed for them. Are these theories flawed and in disagreement with observation solely because static fields were assumed? Because we used uniform electric and magnetic fields in a theory that predicted the symmetry point groups of magnetic crystals that would respond isotropically to such fields, and that would therefore qualify as NRBI media, our theory is dismissed as 'unphysical'. W and L also dismissed, in this context, the work of other authors cited in RS. Furthermore, according to W and L, our symmetry prediction is '*inconsequential* as a physical sample of that material cannot be produced'. By the same token, other symmetry predictions concerning effects in static fields are also inconsequential, for example that piezoelectricity may occur in crystals whose point groups lack a centre of inversion. If W and L are correct, no physical samples of piezoelectric crystals can be produced either.

Reply 4. The possible existence of a Tellegen medium (discussed in section 5 in RS) is also dismissed by W and L because we 'invoke unphysical entities such as time-independent fields and instantaneously responding materials'. This also misrepresents our case. We showed that the Van Vleck proof is inapplicable at the level of laboratory-made 'macroscopic molecules', so that in principle a Tellegen fluid can be produced.

References

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[3] Weiglhofer W S 1994 *J. Phys. A: Math. Gen.* **27** L871
[4] Lakhtakia A and Weiglhofer W S 1996 *IEEE Trans.* **MTT-42** 1715