IS THERE A STATIC MAGNETIC FIELD OF THE PHOTON?

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Some logical deficiences in Evans' work on the static magnetic field of the photon are pointed out. Physical consequences of this field are analyzed, from which it is argued that the field does not exist.

Key words: photon, inverse Faraday effect, Evans' $B^{(3)}$ field.

1. INTRODUCTION

In a series of publications, M.W. Evans has attempted to deduce the existence of a static magnetic field of the photon, denoted by $B^{(3)}$ (see, for instance, [1–5]). The basic proposition is that a photon, which in Evans' work is always implicitly defined as an excitation of a circularly polarized plane wave mode with wave vector $k$, not only possesses the usual transverse magnetic field perpendicular to $k$, but also a magnetic field component along the $k$ vector. The field $B^{(3)}$ is claimed to be a realistic magnetic field, e.g., satisfying the Maxwell equations, and being able to magnetize matter.

One of the physical reasons for assuming the existence of this magnetic field is the experimental evidence for the inverse Faraday effect. This effect, according to conventional theory, is due to the AC-Stark shifts of magnetic sublevels of the ground state of an atom or molecule due to the nonresonant coupling to other states. It can be derived as
follows [6]. Suppose we have a multiplet of states $|M\rangle$ in the ground state that are nonresonantly coupled to states $|i\rangle$ by a monochromatic light field propagating in the $z$ direction:

$$E = \text{Re}(E \exp(-i\omega t)),$$
$$B = \text{Re}(B \exp(-i\omega t)),$$

(1)

with $E$ and $B$ the complex amplitudes of the electric and magnetic fields (which contain the spatial factor $\exp(ikz)$). After adiabatic elimination of the states $|i\rangle$, one finds the effective Hamiltonian in the subspace spanned by the states $|M\rangle$, which contains the terms

$$\langle M'|H_{\text{eff}}|M\rangle = \sum_i \frac{\langle M'\cdot E \rangle \langle \mu_M \cdot E^* \rangle}{E_M + \hbar \omega - E_i} + \sum_i \frac{\langle M'\cdot E^* \rangle \langle \mu_M \cdot E \rangle}{E_M - \hbar \omega - E_i},$$

(2)

with $\mu$ the atomic dipole moment operator. Rewriting this expression yields, among others, a term proportional to the cross product $E \times E^*$, namely

$$\langle M'|H_{\text{eff}}^{\text{mag}}|M\rangle = -\sum_i \frac{\hbar \omega}{(E_M - E_i)^2 - \hbar^2 \omega^2} (E \times E^*) \cdot (\mu_{M'} \times \mu_M).$$

(3)

The vector $E \times E^*$ is proportional to the spin angular momentum density of the light [7]. Since the $z$ component of the atomic matrix element multiplying this vector is proportional to $\langle M'|J_z|M\rangle$ [6], this part of the effective Hamiltonian takes the form of the interaction between the magnetization of the atom and the spin of the field. In other words, it is the interaction between the atomic magnetic dipole moment and a fictitious or effective magnetic field proportional to $E \times E^*$. This latter effective magnetic field, already interpreted this way in [6], is now considered to imply the existence of a real magnetic field

$$B^{(3)} = \frac{iE \times E^*}{E_0 c},$$

(4)

with $E_0 = |E| \equiv cB_0$. This definition is then rewritten in the form

$$B^{(3)} = JB_0 / \hbar,$$

(5)

with $J$ the (spin) angular momentum of the electromagnetic field.

Here I want to argue that $B^{(3)}$ is a quantity proportional to the angular momentum (or density) of the electromagnetic field, with the