Light, a Flux of Electric Dipole Photons

J.P. Wesley

Abstract

Particles to be viewed macroscopically as an electrodynamic light wave must make up a coherently spatially arrayed flux of electric dipole photons. The photons must move as a function of time and initial conditions along trajectories prescribed by the integrals of their velocity $\mathbf{w}$*, given by* $\mathbf{w} = \mathbf{S}/E$*, where* $\mathbf{S} = \nabla\Psi\partial\Psi/\partial t$*,* $E = (\nabla\Psi)^2/2 + (\partial\Psi/\partial tc)^2/2$*, and* Ψ *is a solution to the wave equation. Since a distribution of induced electric dipoles in a medium yields a resultant electric field, the polarization, it may be assumed that a flux of photons as electric dipoles in free space will yield the observed electric* $\mathbf{E}$ *field of a light wave. It is shown that such a flux of electric dipoles generates the observed magnetic* $\mathbf{B}$ *field for a transverse light wave. No magnetic field accompanies a longitudinal light wave, the electric dipoles being aligned in the direction of propagation.*

Key words: light, electric dipole photon flux

1. PRELIMINARY COMMENTS

Macroscopically, the behavior of light as an electromagnetic wave is successfully prescribed by classical physical optics and electromagnetic field theory involving mathematical functions continuous over all space and time. In order for this successful macroscopic theory to be compatible with light as a flux of photons, a vast number of photons, acting en masse, must be involved.

However, the continuous macroscopic picture of light is valid only so long as *coherency* exists. It is now known that light from ordinary sources radiates as infrequent short bursts or clusters of very many coherent or phase-coupled photons. Ordinary light sources *lase.* The evidence now indicates that the phase behavior of light is a multiple-photon phenomenon. This paper is not concerned with the possibility of detecting individual photons, whether this has been achieved, as frequently claimed, or not. The detection of infrequent bursts is often mistakenly interpreted as the observation of individual photons. The present investigation is limited to the classical picture appropriate for coherent bursts of photons.

For light to be a flux of photons, three immediate basic questions need to be answered: (1) How can a flux of particles yield the observed periodicity of waves and interference patterns? (2) What are the photon trajectories that can be described by the mathematics of waves? (3) What are the physical properties of a photon that permit an ensemble of photons to exhibit the macroscopically observed electric and magnetic fields of a light wave?

2. WAVES AS TRANSLATED SPATIALLY PERIODIC ARRAYS

Ordinarily, the concept of a *wave* is that of a periodic propagated phenomenon in a medium, where the medium itself does not propagate, such as a sound wave in air, a water wave on water, or a wave propagated down a rope. However, precisely the same mathematical wave can be generated by a periodic structure translated with the wave velocity past a stationary observer. For example, a wire coat hanger bent sinusoidally, such as to have a y position given by

$$y = y_0 \sin\left(\frac{2\pi x}{\lambda}\right), \tag{1}$$

where y_0 is the amplitude and λ is the wavelength, when translated with the velocity v in the x direction past a stationary observer, yields a propagating wave given by

$$y = y_0 \sin\left(\frac{2\pi(x - vt)}{\lambda}\right), \tag{2}$$

with a frequency $\nu = v/\lambda$.

Since light propagates through empty space, no medium being necessary, light must be a flux of particles arranged in a periodic array that is translated with the velocity c. The array must be spatially sinusoidal in order to generate a sinusoidal propagating wave.

The orderliness of the array pattern defines "coherence." When the sinusoidal spatial periodicity is broken, the wave before the break is then "incoherent" with respect to the wave after the break. It is observed that coherence is produced in sources where the photons are crowded together in a small volume. It is observed that light from ordinary sources remains coherent for about 10^{-9} s, so the coherence spatially is about 1 m in length. In lasers, where a greater density of photons can be crowded into the source, the spatially ordered array propagated from such a source can be up to 100 m in length. Electrons and all quantum particles exhibiting wave behavior have the same coherence properties as light.

The sinusoidal spatial variation might be a variation in the density of photons in the direction of propagation; it might also represent some other detectable property of photons that varies sinusoidally in space.

3. PHOTON TRAJECTORIES YIELDING WAVE BEHAVIOR

The wave-particle problem dates back to Newton's day. Is light a flux of particles, as championed by Newton, or is light a propagated perturbation in a medium or luminiferous ether, as championed by Huygens? The periodic nature of light was first recognized by Newton, who measured the wavelength of light with his Newton's rings interference observations. Huygens envisioned light as merely a sort of shock wave devoid of any periodic character.

The wave-particle problem was finally resolved by Wesley,[1–14] who investigated the problem extensively. The particle kinematics and dynamics that produce wave behavior may be readily obtained by noting that the particle trajectories must necessarily be along the lines of the wave energy flux $\mathbf{S}$ with an energy density E. The wave nature of light in a region with no sources may be described, subject to appropriate boundary conditions, by solutions to the wave equation,

$$\nabla^2\Psi - \frac{\partial^2\Psi}{\partial t^2 c^2} = 0, \tag{3}$$

where c is the wave velocity. The energy flux $\mathbf{S}$ and density E are given by

$$\mathbf{S} = -\nabla\Psi \frac{\partial\Psi}{\partial t}, \qquad E = \frac{(\nabla\Psi)^2}{2} + \frac{(\partial\Psi/\partial tc)^2}{2}. \tag{4}$$

The wave-function Ψ is a mathematical generating function that may be conveniently identified with different physical properties to fit different physical situations. The particle velocity necessary to yield the wave energy characteristics is given by

$$\mathbf{w} = \frac{\mathbf{S}}{E} = \frac{d\mathbf{r}}{dt}, \tag{5}$$

where $\mathbf{r}$ is the position of a particle. The velocity $\mathbf{w}$, given by (5), is a function of space and time (as in hydrodynamics). The motion along the appropriate discrete trajectories, as explicit functions of the time and initial conditions, is then given by integrating (5); thus

$$\int\frac{dx}{S_x} = \int\frac{dy}{S_y} = \int\frac{dz}{S_z} = \int\frac{dt}{E}, \tag{6}$$

where the constants of integration may be expressed in terms of the initial conditions.

For particles of mass m, such as electrons, exhibiting wave behavior, the force $\mathbf{F}$ on an individual particle that makes it follow these trajectories is given by

$$\mathbf{F} = m\mathbf{a} = m\frac{d\mathbf{w}}{dt} = m\frac{d(\mathbf{S}/E)}{dt}. \tag{7}$$

For photons the mass m may be chosen as $h\nu/c^2$, where h is Plank's constant and ν is the frequency. The "wave potential" U yielding this force is then given by

$$U = E_0 - \frac{mw^2}{2} = E_0 - m\frac{(\mathbf{S}/E)^2}{2}, \tag{8}$$

where E_0 is the total classical energy appropriate for slow particles and is a constant of the motion. For steady-state flow, the case of primary interest, $\mathbf{w}$ is a function of position only; U is then also a function of position only. The rate of doing work on a particle is

$$\mathbf{F}\cdot\mathbf{w} = -\frac{dU}{dt} = \mathbf{w}\cdot\nabla U, \tag{9}$$

so that, in this case, the force becomes

$$\mathbf{F} = -\nabla U, \tag{10}$$

as it should.

Explicit examples of the particle motion and the trajectories that yield wave behavior and interference patterns, such as Young's double pinhole interference and standing waves in a box, can be found in the literature.[7–11,13,14]

Although only scalar waves have been considered here, the results are perfectly general because vector waves may always be represented by two scalar waves, such as for electrodynamic waves.[15]

4. THE ELECTRIC FIELD PRODUCED BY A DISTRIBUTION OF ELECTRIC DIPOLES

A distribution of induced electric dipoles in a medium can give rise to an electric field, the polarization **P**, defined by

$$\mathbf{P} = n\mathbf{d} = nq\mathbf{L}, \tag{11}$$

where n is the number density of electric dipoles of dipole moment $\mathbf{d} = q\mathbf{L}$, where q is the induced plus and minus charge separated by the distance **L**.[16] The resultant electric field in the medium **D** is then given by the applied field **E** and the polarization field **P**; thus

$$\mathbf{D} = \mathbf{E} + \mathbf{P}. \tag{12}$$

It becomes immediately obvious that the electric field **E** in empty space can be produced by a distribution of electric dipoles. This means that light, which exhibits an electric field **E**, must be a distribution of electric dipole photons. The electric dipole moment of a photon to produce the observed electric field **E** is then given by

$$\mathbf{d} = \frac{\mathbf{E}}{n} = \left(\frac{\hbar\omega}{E}\right)\mathbf{E}, \tag{13}$$

where $n = E/\hbar\omega$ is the number density of photons, $\hbar = h/2\pi$, ω is the angular frequency, and E is the energy density.

5. THE MAGNETIC FIELD GENERATED BY A FLUX OF ELECTRIC DIPOLE PHOTONS

Since light is generally a transverse electromagnetic wave with a magnetic **B** field transverse to the electric **E** field, it will be shown that the flux of electric dipole photons generates this transverse magnetic **B** field. A row of electric dipoles distributed with the uniform linear density σ along the x axis with charges $+q$ at $y = +L/2$ and $-q$ at $y = -L/2$, when translated with the velocity v in the x direction, yields a positive current $I = +\sigma qv$ in the x direction along $y = +L/2$ and a current $I' = -\sigma qv$ in the x direction along $y = -L/2$. According to elementary electrodynamic theory, these linear currents generate a magnetic **B** field in the negative z direction on the xy plane for $y < |L/2|$ and a positive **B** field on the xy plane for $y > |L/2|$.

It may, thus, be readily concluded that a two-dimensional array of such dipoles in the xy plane, when translated in the x direction, will generate a **B** field in the negative z direction over the xy plane. Similarly, a resultant **B** field is generated by a volume distribution of such electric dipoles when translated with the velocity v.

If a volume array of electric dipoles has a dipole moment varying sinusoidally in the x direction, then the magnetic **B** field generated will also vary sinusoidally when the array is moved with the velocity v in the x direction.

The exact mathematical proof of this magnetic field generated by an array of sinusoidally varying electric dipoles translated with the velocity c may be obtained from Maxwell's equations, which are appropriate for a plane-polarized transverse electromagnetic wave. In particular, the electric field produced by such an array of moving electric dipoles is given by

$$\mathbf{E} = \mathbf{e}_y A \sin\left[\frac{2\pi(x - ct)}{\lambda}\right], \tag{14}$$

where from (11) the amplitude $A = nd$. In empty space Maxwell's equations provide a self-consistency condition; so, if an electric field **E** is given by (14), then a magnetic field **B** must necessarily exist such that

$$\nabla \times \mathbf{E} + \frac{\partial \mathbf{B}}{\partial tc} = 0, \quad \frac{\partial \mathbf{E}}{\partial tc} - \nabla \times \mathbf{B} = 0, \tag{15}$$

which then yields the nonzero magnetic field generated as

$$\mathbf{B} = \mathbf{e}_z A \sin\left[\frac{2\pi(x - ct)}{\lambda}\right]. \tag{16}$$

It is thus clear that light, as a transverse plane-polarized wave, is a flux of a spatially coherent sinusoidal array of electric dipole photons aligned transversely to their translational velocity c.

Since longitudinal electrodynamic waves have also been demonstrated to exist,[17] light can also exist as a longitudinal electric wave where no magnetic field is involved. In this case the electric dipole photons are all aligned with their electric dipole moments in the direction of propagation, so no magnetic field can be generated.

6. SPECULATION CONCERNING A POSSIBLE PHOTON MODEL

Since charge appears to be quantized as the electron charge e, the electric dipole photon might be an electron-positron pair separated by the distance $\mathbf{L}$ to yield an electric dipole moment $\mathbf{d} = e\mathbf{L}$. The half spins of the electron and the positron $\hbar/2$ might then add to yield the unit spin $\hbar$ of the photon. Since the magnetic moment of the positron relative to its spin is opposite to the relative orientation of the magnetic moment and the spin of the electron, the net magnetic moment of such an electron-positron pair would yield the zero magnetic moment of the photon.

If the electrostatic force of attraction e^2/L^2 were balanced against the force of repulsion between the two antiparallel magnetic moments, $6\mu_m^2/L^4$, where $\mu_m = \hbar e/2cm_e$, would yield a separation distance $L = 4.73 \times 10^{-11}$ cm. This separation distance might seem reasonable as compared with the Compton wavelength of a single free electron of 2.43×10^{-10} cm. Unfortunately, the energy of the electron-positron pair would have to equal the photon energy; thus

$$\hbar\omega = 2c^2 m_e - \frac{e^2}{L} + \frac{2\mu_m^2}{L^3} > 2c^2 m_e, \tag{17}$$

which would mean that such an electron-positron pair could not be stable, the photon energy $\hbar\omega$ being drastically less than $2c^2 m_e$.

The partial success of this speculation indicates that perhaps an adjustable double plus-minus spinning ring model for the electron[18] might work. No further speculation is warranted here.

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Résumé

Les particules quand sont considérées d'une façon macroscopique comme une onde électrodynamique de lumière doivent être un flux de photons de dipôles électriques arrangé dans un ordre spatial cohérent. Les photons doivent bouger en tant que fonction de temps et conditions initiales au long des trajectoires prescrites par les intégrales de leur vitesse w, où $\mathbf{w} = \mathbf{S}/E$, $\mathbf{S} = \nabla\Psi\partial\Psi/\partial t$, $E = (\nabla\Psi)^2/2 + (\partial\Psi/\partial tc)^2/2$, *et* Ψ *est une solution de l'équation de l'onde. Comme une distribution de dipôles électriques induits dans un medium produit un champ électrique — la polarisation — on peut assumer alors qu'un flux de photons comme dipôles électriques dans l'espace vide pourrait produire le champ électrique* $\mathbf{E}$ *observé d'une onde de lumière. Il est démontré qu'un flux de dipôles électriques produit le champ magnétique* $\mathbf{B}$ *observé de l'onde de lumière transversale. Aucun champ magnétique n'accompagne une onde de lumière longitudinale, car les dipôles électriques sont alignés dans la direction de la propagation.*

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J.P. Wesley
Weiherdammstrasse 24
78176 Blumberg, Germany