About Energy of Photon

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Abstract

There is a widespread view in contemporary physics that the electric field of an electromagnetic wave is in the phase with the magnetic field. This statement is incorrect. The article discloses in detail that the above statement leads to violating the law of energy conservation. The right statement is that electric and magnetic fields in the photon are shifted mutually by 90 degrees. In this case the electric field converts to the magnetic field and vice versa. The energy of the photon over time remains constant.

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Set of Maxwell equations [1] for vacuum is:

$$rot\,\boldsymbol{E} = -\,1/c\;\partial\boldsymbol{B}/\partial t, \quad (1)$$
$$rot\,\boldsymbol{B} = 1/c\;\partial\boldsymbol{E}/\partial t, \quad (2)$$
$$div\,\boldsymbol{E} = 0 \quad (3)$$
$$div\,\boldsymbol{B} = 0 \quad (4)$$

where: ***E*** – vector of electric field,
B – vector of magnetic field,
t – time,
c – speed of light.

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Usually the equation system (1….4) is solved independently, i.e., for the electric field the equations (1 and 3) and for the magnetic field the equations (2 and 4) are used. As a result, two independent solutions are arrived at. In the case of a monochromatic wave the expressions for electric field ***E*** and magnetic field ***B*** are:

$$\boldsymbol{E}\,(x,\,t) = \boldsymbol{E}_0 \sin\,(\omega t), \tag{5}$$

$$\boldsymbol{B}\,(x,\,t) = \boldsymbol{B}_0 \sin\,(\omega t), \tag{6}$$

where: $\boldsymbol{E}_0$ and $\boldsymbol{B}_0$ – amplitude of electric and magnetic field.

According to the equations (5, 6) the magnetic and electric fields are mutually orthogonal and the magnetic field wave is in the phase with the electric field wave (fig. 1).

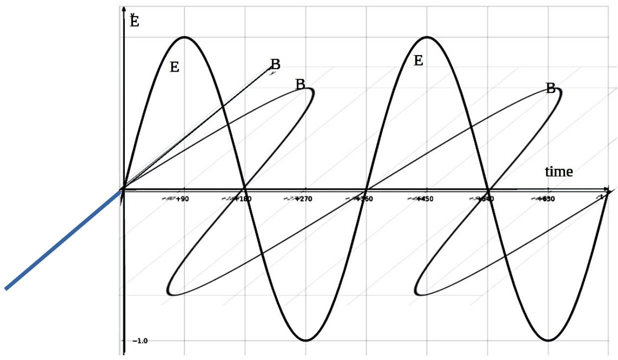

Fig. 1. Electromagnetic field according to equations (5, 6).

The energy density of the electromagnetic field in the Gauss unit system is:

$$w = (\boldsymbol{E}^2 + \boldsymbol{B}^2)/8\pi \tag{7}$$

According to the equations (5, 6) the energy density is:

$$w = (\boldsymbol{E}_0^2 \sin^2(\omega t) + \boldsymbol{B}_0^2 \sin^2(\omega t))/8\pi. \tag{8}$$

Mathematically all the above-mentioned is correct. From the physical point of view it is nonsense because it violates the energy conservation law [2]. Energy emerges from nothing and disappears (fig.2) at the time moments where $\omega t = \pi\, n$.

There n = 1, 2, 3, ...

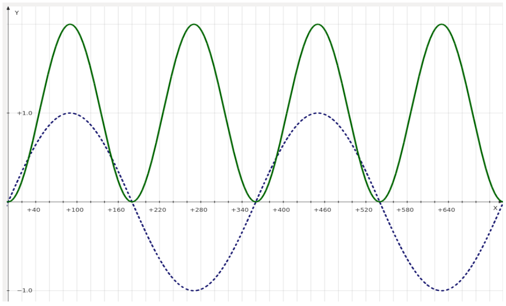

Fig. 2. Energy density (green) according to equation (8) and
synchronous electric field (dashed).
The energy density periodically is equal to zero.

A physically correct solution can be obtained if in the equation (2) the expression of electric field ***E*** is used from (5), i.e., $rot\, \mathbf{B} = 1/c\ \partial(\mathbf{E}_0 \sin(\omega t)) / \partial t$.

The result is: $\mathbf{B}(x, t) = \mathbf{B}_0 \cos(\omega t)$. (9)

Vector ***E*** is shifted according to vector ***B*** by 90 degrees (fig. 3.).

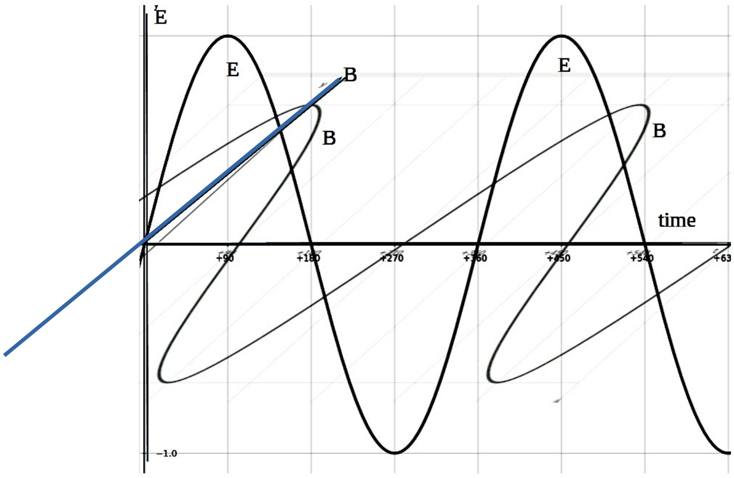

Fig. 3. Electric ***E*** and magnetic ***B*** field of photon.

The energy density is: $w = (\mathbf{E}_0^2 \sin^2(\omega t) + \mathbf{B}_0^2 \cos^2(\omega t))/8\pi$. (10)

In this case the energy is conserved (fig. 4). The energy of the electric field emerges from the magnetic field and vice versa.

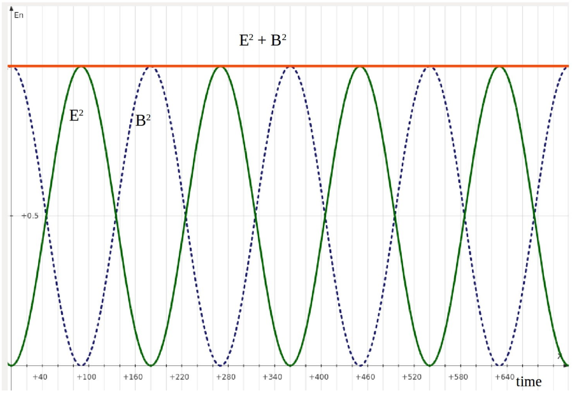

Fig. 4. Electric field energy (green), magnetic field energy (dashed), total energy of photon (orange).

The electric field reaches its maximum when the magnetic field is zero and vice versa. In this way, electric energy converts into magnetic and the magnetic into the electric. The total sum of the energies remains unchanged over time.

References

1. Feynman, R. Solutions of Maxwell's Equations in Free Space. http://www.feynmanlectures.caltech.edu/II_20.html

2. *Encyclopædia Britannica* https://www.britannica.com/science/conservation-law

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