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# The Bipolar Linear *Momentum* transported by the Electromagnetic Waves

Fran De Aquino

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Besides energy, the electromagnetic waves transport linear *momentum*. Then, if this momentum is absorbed by a surface, pressure is exerted on the surface. This is the so-called Radiation Pressure. Here we show that this pressure has a *negative* component (opposite to the direction of propagation of the radiation) due to the existence of the negative linear *momentum* transported by the electromagnetic waves. This fact leads to an important theoretical discovery: the velocity of the electromagnetic waves in free space is not a constant.

**Key words:** Gravity, Gravitation, Electromagnetic Waves, Radiation Pressure.

## 1. Introduction

Electromagnetic waves transport energy as well as linear *momentum*. Then, if this *momentum* is absorbed by a surface, pressure is exerted on the surface. Maxwell showed that, if the incident energy  $U$  is totally absorbed by the surface during a time  $t$ , then the total *momentum*  $q$  transferred to the surface is  $q = U/v$  [1]. Then, the pressure,  $p$  (defined as force  $F$  per unit area  $A$ ), exerted on the surface, is given by

$$p = \frac{F}{A} = \frac{1}{A} \frac{dq}{dt} = \frac{1}{A} \frac{d}{dt} \left( \frac{U}{v} \right) = \frac{1}{v} \frac{(dU/dt)}{A} \quad (1)$$

whence we recognize the term  $(dU/dt)/A$  as the radiation *power density*,  $D$ , (in *watts/m<sup>2</sup>*) arriving at the surface<sup>1</sup>. Thus, if  $v = c$  the *radiation pressure* exerted on the surface is

$$p = \frac{D}{c} \quad (2)$$

Here we show that this pressure has a *negative* component (*opposite to the direction of propagation of the photons*) due to the existence of the negative linear *momentum* transported by the photons. This fact leads to an important theoretical discovery: *the velocity of the electromagnetic waves in free space is not a constant*.

<sup>1</sup> This value is also called of *Poynting vector*.

## 2. Theory

The energy of a harmonic oscillator is quantized in multiples of  $hf$ , and given by

$$E_n = \left(n + \frac{1}{2}\right)hf \quad n = 0, 1, 2, \dots \quad (3)$$

where  $f$  is the classical frequency of oscillation, and  $h$  is the Planck's constant [2]. When  $n = 0$ , Eq. (3) shows that  $E_0 = \frac{1}{2}hf$ . This value is called *energy of the zero point*. Thus, the energy of the harmonic oscillator, at equilibrium with the surrounding medium, does not tend to zero when temperature approaches to absolute zero, but stays equal to  $E_0$ .

In the particular case of *massless oscillators* (photons, for example),  $E_0$  does not correspond to the lowest value of the energy, which the oscillator can have, because, when temperature approaches to absolute zero the oscillator frequency becomes dependent of the temperature  $T$ , as show the well-known expression of the *thermal De Broglie wavelength* ( $\Lambda$ ) for *massless particles* [3, 4], which is given by

$$\Lambda = \frac{ch}{2\pi^{\frac{1}{3}}kT} \quad \Rightarrow \quad \frac{1}{2}hf = \pi^{\frac{1}{3}}kT \quad (4)$$

Then, *the lowest value of the energy*  $\frac{1}{2}hf$ , in the case of the *photon*, for example, will be the value  $\frac{1}{2}hf_0$  correspondent to a critical temperature  $T_c$  very close to absolute zero, and according to Eq. (4), given by

$$\frac{1}{2}hf_0 = \pi^{\frac{1}{3}}kT_c \quad (5)$$

Thus, for  $T \leq T_c$  the energy of the photons is constant and given by  $\frac{1}{2}hf_0$ . Above  $T_c$ , the photon absorbs energy from the surrounding medium, and its energy becomes equal to  $hf$ . Therefore, the energy absorbed by the photon is

$$U = hf - \frac{1}{2}hf_0 \quad (6)$$

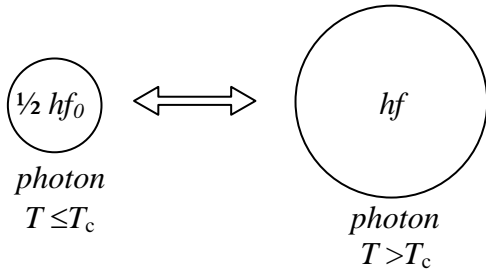


Fig. 1 – Above  $T_c$ , the photon absorbs energy from the surrounding medium, and its energy becomes equal to  $hf$ .

Consequently, the expression of the *momentum*  $q$  transported by the photon with velocity  $\vec{v}$  will be expressed by

$$\begin{aligned} \vec{q} &= \frac{U}{\vec{v}} = \frac{hf - \frac{1}{2}hf_0}{\vec{v}} = \left(1 - \frac{1}{2} \frac{f_0}{f}\right) \frac{hf}{\vec{v}} = \\ &= \left(1 - \frac{1}{2} \frac{f_0}{f}\right) \frac{hf}{\vec{v}} \left(\frac{c}{c}\right) = \left(1 - \frac{1}{2} \frac{f_0}{f}\right) \frac{hf}{c} \left(\frac{c}{\vec{v}}\right) = \\ &= \left(1 - \frac{1}{2} \frac{\lambda}{\lambda_0}\right) \frac{h}{\lambda} \left(\frac{c}{\vec{v}}\right) = \left(1 - \frac{1}{2} \frac{\lambda}{\lambda_0}\right) \frac{h}{\lambda} \vec{n}_r \quad (7) \end{aligned}$$

Equation above shows the existence of a *bipolar linear momentum* transported by the electromagnetic waves. For  $\lambda < 2\lambda_0$  the resultant *momentum* transported by the photon is *positive*, i.e., If this *momentum* is absorbed by a surface, pressure is exerted on the surface, in the same direction of propagation of the photon. These photons are well-known. However, Eq. (7) point to a new type of photons when  $\lambda = 2\lambda_0$ . In this case  $q = 0$ , i.e., *this type of photon does not exert pressure when it incides on a surface*. What means that it does not interact with matter.

Obviously, this corresponds to a special type of photon, which we will call of *neutral photon*. Finally, if  $\lambda > 2\lambda_0$  the resultant *momentum* transported by the photon is *negative*. If this *momentum* is absorbed by a surface, pressure is exerted on the surface, in the *opposite direction of propagation of the photon*. This special type of photon will be denominated of *attractive photon*.

Considering that the critical temperature  $T_c$  should be very close to absolute zero, similar to the critical temperature in which occurs the transition to Bose-Einstein Condensates (*nanoK*) then, according to Eq. (5), the *limit-frequency*  $f_0$  should be of the order of **10Hz** or less. This is the range of the extremely low frequency (ELF) radiation.

The quantization of gravity shows that the *gravitational mass*  $m_g$  and *inertial mass*  $m_i$  are correlated by means of the following factor [5]:

$$\chi = \frac{m_g}{m_{i0}} = \left\{ 1 - 2 \left[ \sqrt{1 + \left(\frac{\Delta p}{m_{i0}c}\right)^2} - 1 \right] \right\} \quad (8)$$

where  $m_{i0}$  is the *rest inertial mass* of the particle and  $\Delta p$  is the variation in the particle's *kinetic momentum*.

Another important equation obtained in the quantization theory of gravity is the new expression for the *momentum*  $q$  of a particle with gravitational mass  $M_g$  and velocity  $v$ , which is given by

$$\vec{q} = M_g \vec{v} \quad (9)$$

where  $M_g = m_g / \sqrt{1 - v^2/c^2}$ ;  $m_g$  is given by Eq.(8), i.e.,  $m_g = \chi m_i$ . Thus, we can write

$$M_g = \frac{\chi m_i}{\sqrt{1 - v^2/c^2}} = \chi M_i \quad (10)$$

Substitution of Eq. (10) into Eq. (9) gives

$$\vec{q} = \chi M_i \vec{v} = \frac{\vec{v}}{c} \chi \frac{h}{\lambda} \quad (11)$$

By comparing Eq. (11) with (7) we obtain

$$v = c \sqrt{\frac{1}{\chi} \left(1 - \frac{f_0}{2f}\right)} \quad (12)$$

In the free space, i.e., in absence of others

electromagnetic fields ( $\chi = 1$ ) the Eq. (12) reduces to

$$v = c \sqrt{\left(1 - \frac{f_0}{2f}\right)} \quad (13)$$

Equation (13) shows that the speed of the electromagnetic waves in free space *is not a constant*. Thus, also the speed of light is not a constant.

Theories proposing a varying speed of light have recently been widely proposed under the claim that they offer a solution to cosmological puzzles [6, 7].

In the case of  $f \ll f_0$ , Eq. (7) shows that the *momentum*  $\vec{q}$  carried by the photon is *negative* (has opposite direction to the velocity  $\vec{v}$  of the photon). Then, in order to compare Eq. (11) with Eq. (7), in this case, we have that change  $v$  for  $-v$  in Eq. (11). The result is

$$v \cong c \sqrt{\frac{f_0}{2\chi f}} \quad (14)$$

This is the expression of the velocity  $v$  of photons with frequency  $f \ll f_0$ .

This equation tells us that, in free space ( $\chi = 1$ ), electromagnetic waves with frequency  $f \ll f_0$  have *velocity much greater than  $c$* .

Next, we will show that this fact does not affect the relativistic factor  $\sqrt{1 - V^2/c^2}$ .

It is known that the interactions are communicated by means of the changing of “virtual” *quanta*. The maximum velocity of these *quanta* is a *constant* called maximum velocity of propagation of the interactions. Currently, it is assumed that this velocity is equal to the velocity of the electromagnetic waves in free space ( $c$ ). This is the reason of the constant  $c$  to appear in the relativistic factor above mentioned. However, Eq. (13) shows that the velocity of the electromagnetic waves in free space is not a constant.

The maximum velocity of the *quanta* of the interactions is the velocity of the *quanta*, which are “virtual” photons. Thus, if the frequency  $f$  of these photons is a constant and  $f \gg f_0$ , then, according to Eq. (13), the maximum velocity of propagation of the interactions is a constant value very close to  $c$ . In this way, the maximum velocity of propagation of the interactions is

not  $c$  neither a velocity greater than  $c$ , but a value *very close to  $c$* . Consequently, the relativistic factor  $\sqrt{1 - V^2/c^2}$  remains valid in practice.

In a general way, the relativistic factor can now be rewritten as  $\sqrt{1 - V^2/c^2(1 - f_0/2f)}$ , where  $f \gg f_0$  is the typical frequency of the mentioned “virtual” photons. In practice, the two factors should be equivalents. However, the degree of equivalence with  $\sqrt{1 - V^2/c^2}$  will depend of the magnitude of the frequency  $f$ .

The fact of the velocities of the *quanta* of the interactions be smaller than  $c$  does not mean that the velocities of some types of electromagnetic waves cannot be greater than  $c$ , as predicted by Eq.(13), in the case of  $f \ll f_0$ . Photons have *null* inertial mass and, in principle, all the particles with null inertial masses can have any velocity.

Generating electromagnetic radiation at extremely-low frequencies is difficult because the long wavelengths require long antennas, extending for hundreds of kilometers. Natural ionospheric currents provide such an antenna if they can be modulated at the desired frequency [8-13]. The generation of ELF electromagnetic radiation by modulated heating of the ionosphere has been the subject matter of numerous papers [14-20].

In 1974, it was shown that ionospheric heater can generate ELF waves by heating the ionosphere with high-frequency (HF) radiation in the megahertz range [14]. This heating modulates the electron’s temperature in the D region ionosphere, leading to modulated conductivity and a time-varying current, which then radiates at the modulation frequency.

Several HF ionospheric heaters have been built in the course of the latest decades in order to study the ELF waves produced by the heating of the ionosphere with HF radiation. Currently, the HAARP heater is the most powerful ionospheric heater, producing ELF radiation with  $f = 2.5\text{Hz}$  [21, 22].

If is possible generate ELF radiation with frequency  $f \approx 1\text{mHz}$ , by means of the above mentioned process, then the veracity of Eq. (14) can be checked. According to Eq. (14), *the velocity of the generated waves should be of the order of  $10c$* .

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