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Superluminal Speed of Photons in the Electromagnetic Near-Field

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Abstract

The possible existence of superluminal particles, which are forbidden by well-known laws of physics, has been studied by many physicists. Some of them confirmed the superluminal speed by their experiments. By using Klein-Gordon wave equation for photons, the author shows that the photon travels at a superluminal speed in an electromagnetic near field of the source and they reduce to the speed of light as they propagate into the far field.

Keywords

Photon, Near-field, Superluminal speed, Electromagnetic radiation

Introduction

E. Recami claimed in his paper [1] that tunneling photons traveling in evanescent mode can move with superluminal group speed inside the barrier. Chu and S. Wong at AT&T Bell Labs measured superluminal velocities for light traveling through the absorbing material [2]. Furthermore, Steinberg, Kwait and Chiao devised an experiment measuring the tunneling time for visible light through an optical filter, consisting of a multilayer coating about m thick, and confirmed superluminal speed [3]. The results obtained by Steinberg and co-workers have shown that the photons seemed to have traveled at 1.7 times the speed of light. Recent optical experiments at Princeton NEC have verified that superluminal pulse propagation can occur in transparent media [4]. These results indicate that the process of tunneling in quantum physics is indeed superluminal, as claimed by E. Recami. Caligiuri and Musha also confirmed the existence of superluminal photons in brain microtubules theoretically [5].

The photon is a type of elementary particle, the quantum of the electromagnetic field including electromagnetic radiation such as light, and the force carrier for the electromagnetic force. The photon has zero rest mass and always moves at the speed of light in vacuum. The single photons travel through space at the group velocity of light. The group velocity of the light wave is thought of as the velocity at which energy or information is conveyed along a wave. The electromagnetic field by photons consists of the near-field and far field around an object, such as a transmitting antenna, or the result of radiation scattering off an object. Far-field strength decreases inversely with distance from the source, resulting in an inverse-square law for the radiated power intensity of electromagnetic radiation. By contrast, near-field E and B strength decrease more rapidly with distance: The one part decreases by the inverse-distance squared, the other part by an inverse cubed law, resulting in a diminished power in the parts of the electric field by an inverse fourth-power and sixth-power, respectively.

The author published a paper that claimed a tiny particle compared with electrons like neutrinos might be generated as a superluminal particle [6]. In this paper, by applying Klein-Gordon equation, it is shown that photons are generated as a superluminal particle and moves at a superluminal speed (i.e. superluminal group velocity of the light wave) in the electromagnetic near-field from the source.

Wave Equation for the Superluminal Photon

From the wave function mathematical description of a particle, taking account the special theory of relativity, the Klein-Gordon equation is considered:

$$i\hbar\frac{\partial\psi}{\partial t} = H\psi\ , \tag{1}$$

Where H is a Hamiltonian given by $H = \sqrt{p^2c^2 + m^2c^4}$ (p : Momentum of the particle, m : Effective mass) and ψ is a wave function of a particle. The following equation can

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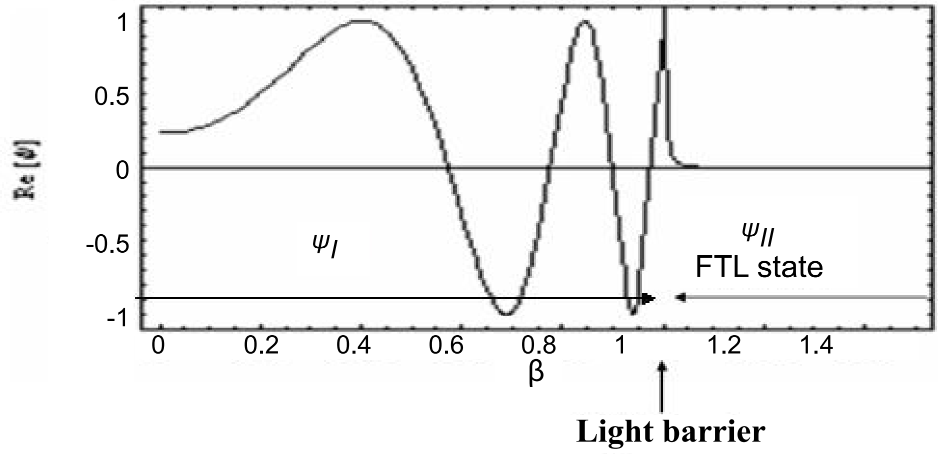

Figure 1: The wave function of a tunneling particle through the light barrier.

be obtained for the accelerating particle [7]

$$\frac{\partial \psi}{\partial p} = -\frac{i}{ma\hbar}\sqrt{p^2c^2 + m^2c^4}\,\psi\,, \tag{2}$$

Where $\hbar$ is the Plank constant divided by 2π, c is the speed of light, and a is a proper acceleration given by $p = mat$.

From Eq. (2), we have the solution given by [7]

$$\psi = C\cdot\exp\left[-i\frac{c}{2ma\hbar}\left(p\sqrt{p^2+m^2c^2} + m^2c^2\log(p+\sqrt{p^2+m^2c^2})\right)\right], \tag{3}$$

Where C is an arbitrary constant.

By introducing the particle linear momentum $p = \frac{mv}{\sqrt{1-v^2/c^2}}$, and the energy $E = \frac{mc^2}{\sqrt{1-v^2/c^2}}$, we have

$$\psi = C\cdot\exp\left[-i\frac{Ec}{2a\hbar}\sqrt{1-\beta^2}\left(\frac{\beta}{1-\beta^2} + \log\left(\frac{E}{c}\right) + \log(1+\beta)\right)\right], \tag{4}$$

Where $\beta = v/c$.

The proper acceleration of a particle is determined as if the photon is generated in a quantum region, with size l [8].

Considering that $m_e = \Delta E/c^2$ (equivalent mass of a photon) and $\Delta t = l/c$, and in addition taking care of the uncertainty principle for momentum $\Delta p \cdot l \approx \hbar$, and energy $\Delta E = \Delta p \cdot c$, then the proper acceleration of the photon is estimated [9]:

$$a \approx \frac{1}{m_e}\frac{\Delta p}{\Delta t} = \frac{c^2}{l}, \tag{5}$$

When we let $E = \hbar\omega$, we obtain wave functions for subluminal speed as [10] ($v < c$):

$$\psi = C\cdot\exp\left[-i\frac{\omega\, l}{2c}\sqrt{1-\beta^2}\left(\frac{\beta}{1-\beta^2} + \log(\hbar\omega/c) + \log(1+\beta)\right)\right], \tag{6.1}$$

and for superluminal speed ($v > c$):

$$\psi_* = C\cdot\exp\left[-\frac{\omega\, l}{2c}\sqrt{\beta^2-1}\left(\frac{\beta}{\beta^2-1} - \log(\hbar\omega/c) - \log(1+\beta)\right)\right], \tag{6.2}$$

Where ω is an angular frequency of the particle and β is the ratio of the particle velocity divided by the light speed.

Figure 1 shows the wave function for the highly accelerated particle, which shows the possibility of tunnelling through the light barrier.

If we consider the light barrier as a potential barrier, the probability of a particle to tunnel through the light barrier can be estimated in the WKB approximation and it is given by

$$T \approx |\psi_*|^2/|\psi|^2 = \exp\left[-\frac{\omega\, l}{c}\sqrt{\beta^2-1}\left(\frac{\beta}{\beta^2-1} - \log(\hbar\omega/c) - \log(1+\beta)\right)\right], \tag{7}$$

Supposing that the size of the quantum region l is approximately equal to the Plank length l_p, we have

$$T(\omega) \approx \exp\left[-\frac{\omega}{c}l_p\sqrt{3}\left(\frac{2}{3} - \log(\hbar\omega/c) - \log 3\right)\right], \tag{8}$$

Obtained after inserting $\beta \approx 2$, a value that can be estimated from the uncertainty principle [11].

Then Equation (8) can be rewritten under the form

$$T(\omega) \approx \exp[-l_p\omega(\gamma - \varepsilon\log\omega)], \tag{9}$$

Where

$$\gamma = \frac{2 - 3\log(\hbar/c) - 3\log 3}{\sqrt{3}c} \approx 5.62\times 10^{-7}, \tag{10.1}$$

and

$$\varepsilon = \sqrt{3}/c \approx 5.77\times 10^{-9}. \tag{10.2}$$

Probability of a Photon to Tunnel through the Light Barrier

From Equation (9), we can estimate the probability of a photon to tunnel through the light barrier, represented graphically in Figure 2. In this figure, the horizontal line is for the radial frequency of the photon and the vertical line is for the probability of photons to tunnel through the light barrier.

From this figure, the probability of a photon in a superluminal state almost becomes unity up to the Plank frequency (1.85 Hz), and it is seen that the photon is generated as a

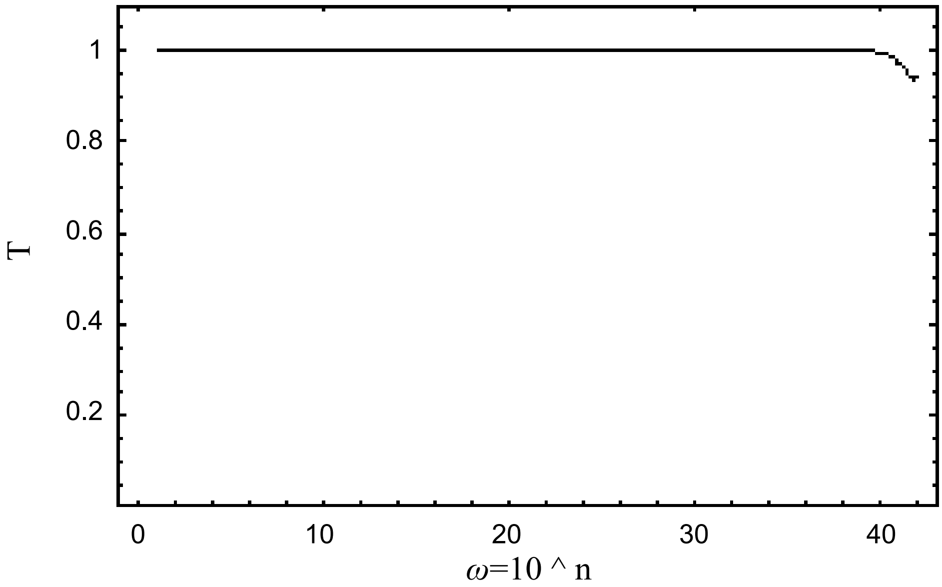

Figure 2: Probability of a photon to tunnel through the light barrier.

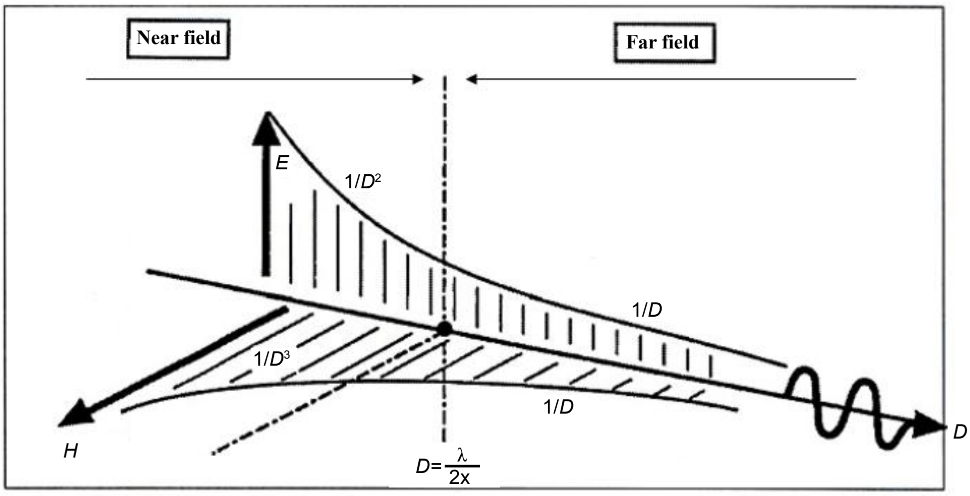

Figure 3: The near and far electromagnetic fields.

superluminal particle. From Figure 1, it can be seen that a tunneling particle through the light barrier returns to the original state within a finite length of time, which can be estimated by the uncertainty principle. The difference of momentum Δp of the photon in an original state at the source and the photon in a superluminal state can be estimated to be $\Delta p = p$, where p is the momentum of the photon in a superluminal state. As the momentum of the photon can be described as $p = \hbar \cdot k = h / \lambda$, then from the uncertainty principle, $\Delta p \cdot \Delta x \approx \hbar$, we get

$$\Delta x \approx \frac{\hbar}{p} = \frac{\lambda}{2\pi}, \quad (11)$$

Which represents the traveling distance of a photon in a superluminal state.

This value coincides with the region of the near field of the electromagnetic wave as shown in Figure 3 and we can conclude that photons moves in a near field from the source at the superluminal speed and reduce to the speed of light (i.e. group velocity of the light wave) as they propagate into the far field.

W. D. Walkers obtained the same result for the electromagnetic wave by using the electromagnetic theory [12-14], and he claimed that it should be possible to reduce the time delay by monitoring lower frequency EM field in the electromagnetic near-field.

Conclusion

From the above theoretical analysis, it is seen that photons propagate at superluminal speed in the electromagnetic near-field from the source and reduce to the speed of light as they propagate into the far field. This phenomenon can be applied for speeding up the processing time of photonic computer systems.

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