# Can Light Signals Travel Faster-than-C in Vacuum?

## Presented at CCFP 2006, Nizhny Novgorod

Prof. Heidi Fearn • Department of Physics, California State University Fullerton, Fullerton, CA 92834

## Introduction

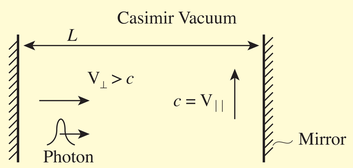
Relativistic causality implies that the front velocity of the pulse cannot travel faster than the speed of light in a vacuum. The front velocity of the pulse is that part of the wave packet that has the highest UV frequency components. This corresponds to a discontinuity (non-analytic cut) in the pulse. This is the speed at which information flows.

### *Scharnhorst Effect*

1. Scharnhorst, Phys. Letts. B236, 354 (1990) Feb.

2. Barton, Phys. Letts. B237, 559 (1990) Mar.

3. Scharnhorst, Annals. of Phys. 7, 700 (1998).




$$\Delta n \approx -\frac{\alpha^2}{(mL)^4}\frac{11\pi^2}{2^2 3^4 5^2} \text{ and } c_\perp = \frac{c}{n} \approx (1-\Delta n)c > c$$

$$\frac{\Delta c}{c} \sim \frac{1.6\times 10^{-60}}{L^4} \text{ and for } L = 1\mu m \text{ we get } \frac{\Delta c}{c} \approx 1.6\times 10^{-36}$$

According to [1] above, $\Delta c/c$
"obviously is far beyond any experimental reach".

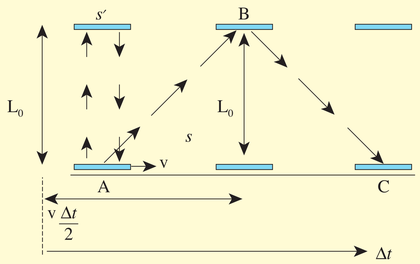
## Vacuum effects due to Dirac Sea

- The electron-positron (Dirac) field profoundly alters the properties of the vacuum in QED relative to those of the classical vacuum: It induces non-linearity's in Maxwell's eqns. and a consequent scattering of light by light.
- The non-linearity's, jointly with mirror induced changes in the ZP Maxwell field, (between parallel mirrors) can cause c to change or the vacuum to amplify. Not sure which ?

## When do the Dispersion relations apply?

- ***Topic of current research--***
- Toll, Phys. Rev. 104, 1760 (1956)- dispersion relations connect the Re. and Im. parts of the diagonal elements of the scattering matrix.
- Dispersion relations used in QFT first by Gell- Mann, Thirring and Goldberger , Phys. Rev. 95, 1612 (1954).
- Is there a minimum length scale involved which the wavelength of light is not allowed to fall below? How many atoms constitutes the minimum number before you can apply the idea of a refractive index? Is something defined for the vacuum?
- Are we misusing the dispersion relations and idea of refractive index for vacuum?

## Time Dilation




### Light Clock Experiment

Assume you have a Scharnhorst type experiment in progress between the mirrors. The velocity in different frames (one with a Scharnhorst and one without) will measure different velocities perpendicular to the mirrors and hence register different times.

$s'$ frame of moving light pulse clock
$s$ is stationary lab frame.

Path length of moving pulse measured in $s$ = AB + BC

$$c\Delta t = 2\left(L_0^2 + \left(v\frac{\Delta t}{2}\right)^2\right)^{1/2}$$

Square

$$c^2\Delta t^2 = 4L_0^2 + v^2\Delta t^2$$

$$\Delta t^2 (c^2 - v^2) = 4L_0^2$$

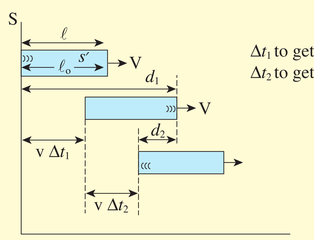
$$\Delta t = \frac{2L_0}{(c^2 - v^2)^{1/2}} = \frac{2L_0/c}{(1 - v^2/c^2)^{1/2}}$$

Proper time as measured on the moving clock

$$\Delta t_o = 2L_0/c$$

$$\Rightarrow \boxed{\Delta t = \gamma\,\Delta t_0}, \quad \gamma = \frac{1}{(1 - v^2/c^2)^{1/2}}$$

## Lorentz Contraction




$\Delta t_1$ to get from left to right
$\Delta t_2$ to get from back to left

proper length of clock = $\ell_o$ (as measured in $s'$)
proper time for one round trip = $\Delta t_0 = 2\ell_0/c$ (as measured in $s'$)

$$d_1 = \ell + v\,\Delta t_1 = c\,\Delta t_1 \Rightarrow \ell = \Delta t_1 (c - v)$$

$$d_2 = \ell - v\,\Delta t_2 = c\,\Delta t_2 \Rightarrow \ell = \Delta t_2 (c + v)$$

$$\Delta t = \Delta t_1 + \Delta t_2 = \frac{\ell}{(c - v)} + \frac{\ell}{(c + v)} = \frac{2\ell c}{(c^2 - v^2)} = \frac{2\ell/c}{(1 - v^2/c^2)}$$

time dilation $\Delta t = \gamma\,\Delta t_0 = \gamma\,2L_0/c$

$$\Rightarrow \Delta t = \Delta t_1 + \Delta t_2 = \frac{2L_0/c}{(1 - v^2/c^2)} = \frac{2\ell/c}{(1 - v^2/c^2)} \rightarrow \boxed{\ell = \ell_0 (1 - v^2/c^2)^{1/2}}$$

### Another more conclusive Light Clock experiment

Remember, the change in c predicted by the Scharnhorst effects is dependent on the distance between the parallel mirrors. If the distance between the mirrors is different in one frame to another in relative motion-velocity of light becomes frame dependent.

What value of c do we use in the Lorentz transformations? How do we agree on time dilation and Lorentz contraction.

## Serious problems with violation of SR…

- QED as we know it (at low to semi high energies) requires SR and causality! The commutation relations depend on it.
- High energy QED may have problems.. May not depend on SR. Radiation reaction could be re-addressed for example… possibility of removing Landau poles and all inconsistencies like run-aways and pre-acceleration.
- Adler- strong magnetic field effects? Faster-than-c signals?

## Clarify: Basics of QED

- The method of quantization of the fundamental Lagrangian in QED requires commutators of the form which do not allow for *signals* (interaction between particles/information of any kind) to pass between two space-like separated points.
- Example of the scalar field quantization follows for simplicity purposes here-

## Quantization of φ for the KG field

Classical action s[φ] is given by, Metric + ---, $x \rightarrow (ct, \vec{x})$

$$s[\varphi] = \int d^4x\, L(x) = \frac{1}{2}\int d^4x\, [\partial^\mu\varphi(x)\partial_\mu\varphi(x) - m^2\varphi^2(x)]$$

We define the conjugate momentum as, $\pi(x) = \dfrac{\partial L}{\partial(\partial_t\varphi)} = \partial_t\varphi = \dot{\varphi}$

The quantized Hamiltonian is; $H = \frac{1}{2}\int d^4x\,(\pi^2 + |\nabla\varphi|^2 + m^2\varphi^2)$

With the equal time commutators defined as;

$$[\varphi(\vec{x},t), \pi(\vec{y},t)] = i\delta(\vec{x} - \vec{y}) \qquad \dot{\varphi} = i[H, \varphi] = \pi(x)$$

$$[\varphi(\vec{x},t), \varphi(\vec{y},t)] = [\pi(\vec{x},t), \pi(\vec{y},t)] = 0 \qquad \dot{\pi} = i[H, \pi] \Rightarrow \Box\varphi + m^2\varphi = 0$$

Page 108, Quantum field theory by Itzykson and Zuber.

## The same holds for 2nd Quantization and for particles of zero mass

$$\varphi(x) = \int \frac{d^3k}{(2\pi)^3}\frac{1}{2\omega_k}\{a(k)e^{-i(k.x)} + a^+(k)e^{i(k.x)}\} \qquad \pi(x) = \dot{\varphi}$$

$$a(k) = \int d^3x\; e^{ik.x}[\omega_k\varphi(x) + i\pi(x)] \qquad [a(k), a^+(k')] = (2\pi)^3 2\omega_k\delta^3(k - k')$$

- E and B-fields and quantized and then vector potentials are quantized into harmonic oscillator raising and lowering operators, a and a+ terms, with similar commutators as above, FT as needed.

## Literature cited

Brillouin, "*Wave propagation and Group Velocity*", Academic Press, New York (1960).

Wang, et al., Nature **406**, 277 (2000).

Stenner et al., Nature **425**, 695 (2003).

Barton & Scharnhorst, J. Phys. Math Gen. **26**, 2037 (1993).

Milloni & Svozil, Phys. Letts. **B248**, 437 (1990).

Ben-Menahem, Phys. Letts. **B250**, 133 (1990).

Itzykson & Zuber, "*Quantum field theory*", McGraw Hill, NY (1965).

Bjorken & Drell, "*Relativistic quantum fields*", McGraw Hill, NY (1965).

Scharnhorst, "The velocities of light in modified QED vacua" http://arxiv.org/hep-th/9810221

Dittrich & Giess, Phys. Rev. D58, 025004 (1998), also their book "*Probing the quantum vacuum*", Springer Press.

Loudon, R."*Quantum theory of Light*" Oxford University Press.

Hatfield, B. "*Quantum field theory of point particles and strings*"

## Acknowledgments

I would like to thank the organizers for inviting me to CCFP 2006.

***Conference Sponsers:***

Air Force Office of Scientific Research

Russian Foundation for Basic Research

European Office of Aerospace Research and Development

## For further information

Please contact *hfearn@fullerton.edu*. More information on this and related projects can be obtained at ***http://physics.fullerton.edu/~heidi***

An older e-print relevant here can be found at, **http://arxiv.org/quant-ph/0310059**. The paper will be published in the Laser Physics journal(3) v17, (2007).

Physics