Superluminal pulse propagation via photonic tunneling

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Seminar: Recent Progress in Nanooptics & Photonics

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"Nothing travels faster than the speed of light with the possible exception of bad news, which obeys its own special laws."

Douglas Adams

Outline

1. Introduction
2. Experiments by Nimtz et. al.
3. Interpretational aspects
4. Conclusion

Introduction

- The speed of light *in vacuo c,* is a fundamental physical constant.

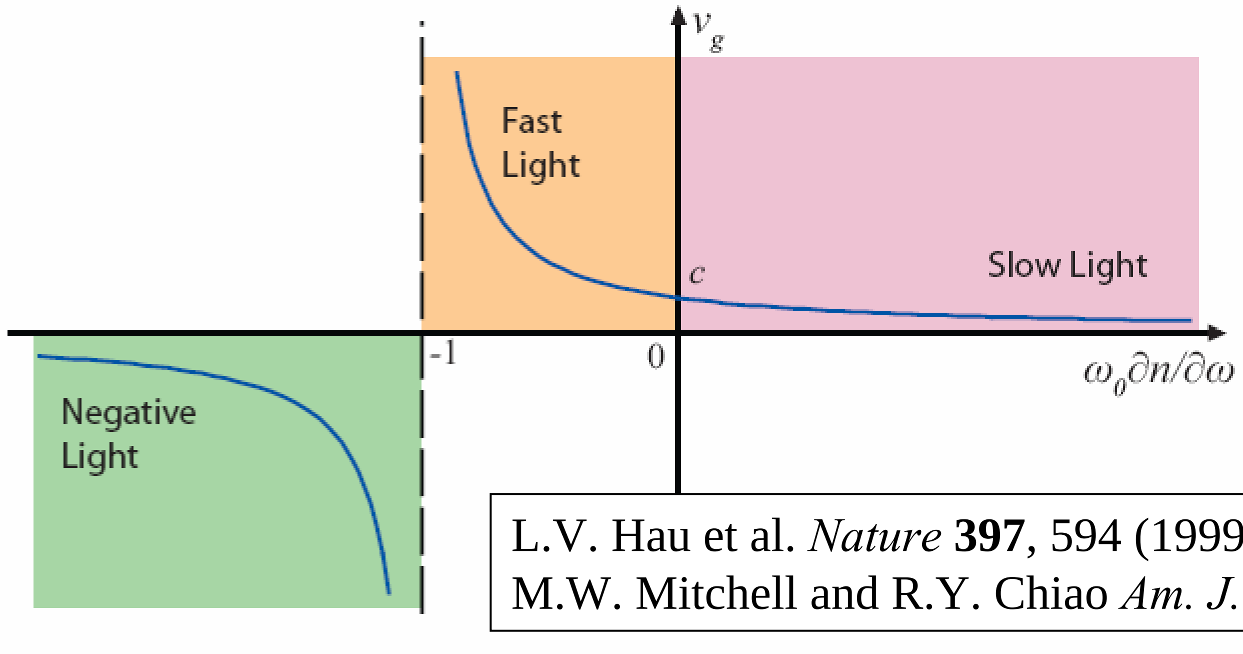
- While material particles and signals are restricted to travel less than *c* according to Einstein's theory of special relativity, not all physical quantities have this restriction.

- For instance: in QED virtual particles may exceed *c* and the envelopes of optical pulses may also travel faster than *c* in dispersive media.

Group Velocity

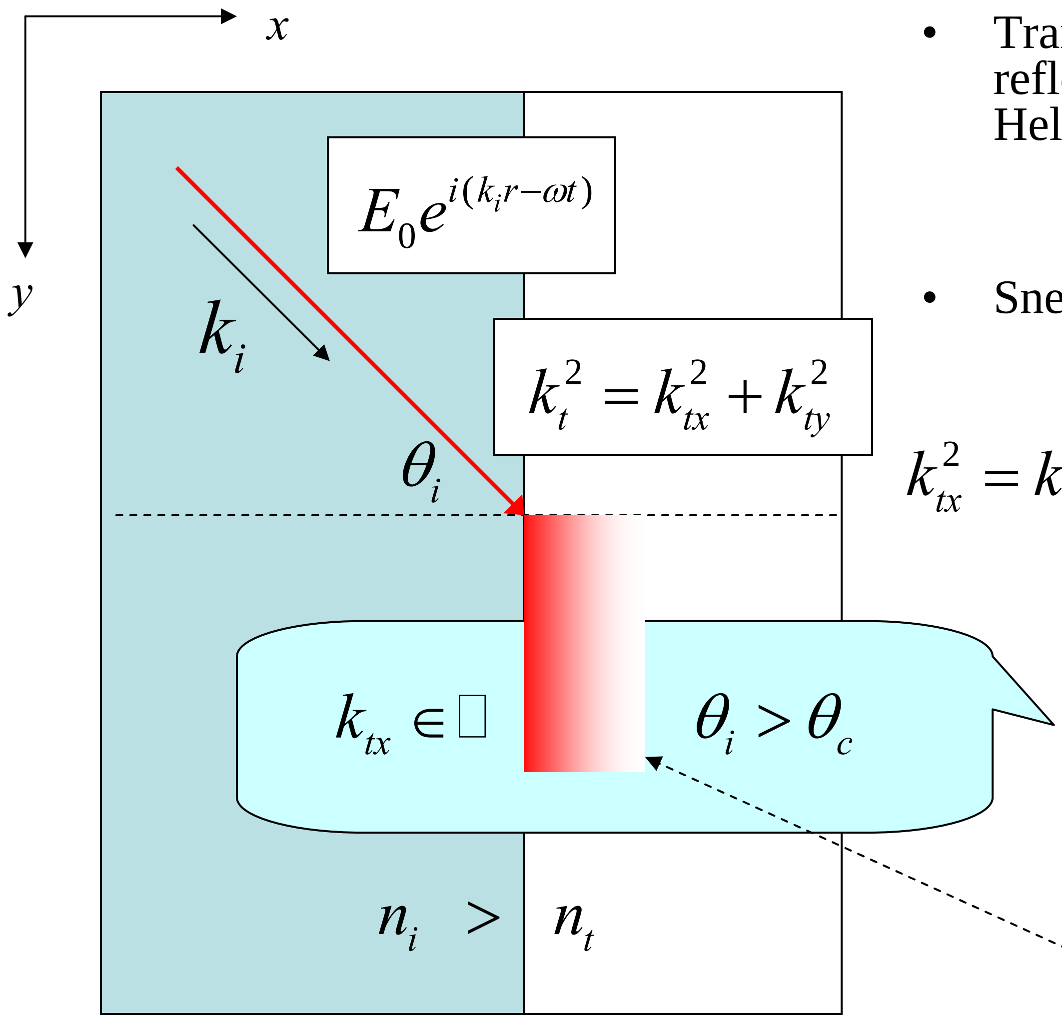
$$v_g = \frac{\partial \omega}{\partial k} = \frac{c}{\partial n(\omega)\omega / \partial \omega} = \frac{c}{n(\omega) + \omega \dfrac{\partial n(\omega)}{\partial \omega}}$$

- v_g can differ from the phase velocity $v_p = c/n$ e.g. in dispersive photonic or electronic systems.



L.V. Hau et al. *Nature* **397**, 594 (1999)
M.W. Mitchell and R.Y. Chiao *Am. J. Phys.* **66**, 14 (1999)

Evanescent fields



- Transmission (evanescent field) and reflection can be obtained from the Helmholtz equation.

$$\nabla^2 E + k^2 E = 0$$

- Snell's law is also instructive.

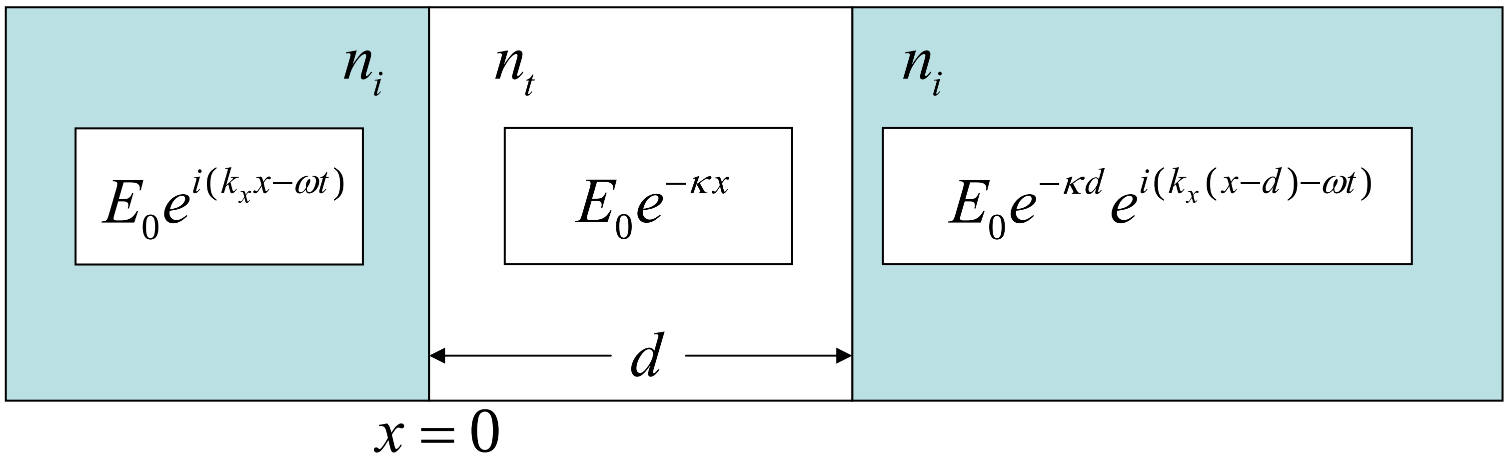
$$k_{tx}^2 = k_t^2 \cos^2 \theta_t = k_t^2 \left[1 - \left(\frac{n_i}{n_t} \right)^2 \sin^2 \theta_i \right]$$

$$i\kappa = k_{tx} = k_t \sqrt{1 - \left(\frac{n_i}{n_t} \right)^2 \sin^2 \theta_i}$$

$$E_0 e^{-\kappa x} e^{i\left(k_t (n_i / n_t) \sin \theta_i y - \omega t\right)}$$

Frustrated Total Internal Reflection

- Consider now only the *x* component.



- The evanescent wave can excite a second traveling wave. (Near field effect.)
- Note, no phase shift within n_t.
- Instantaneous transfer of field.

(Mathematica Demo)

Experiments by Nimtz et al.

On superluminal tunneling

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Abstract

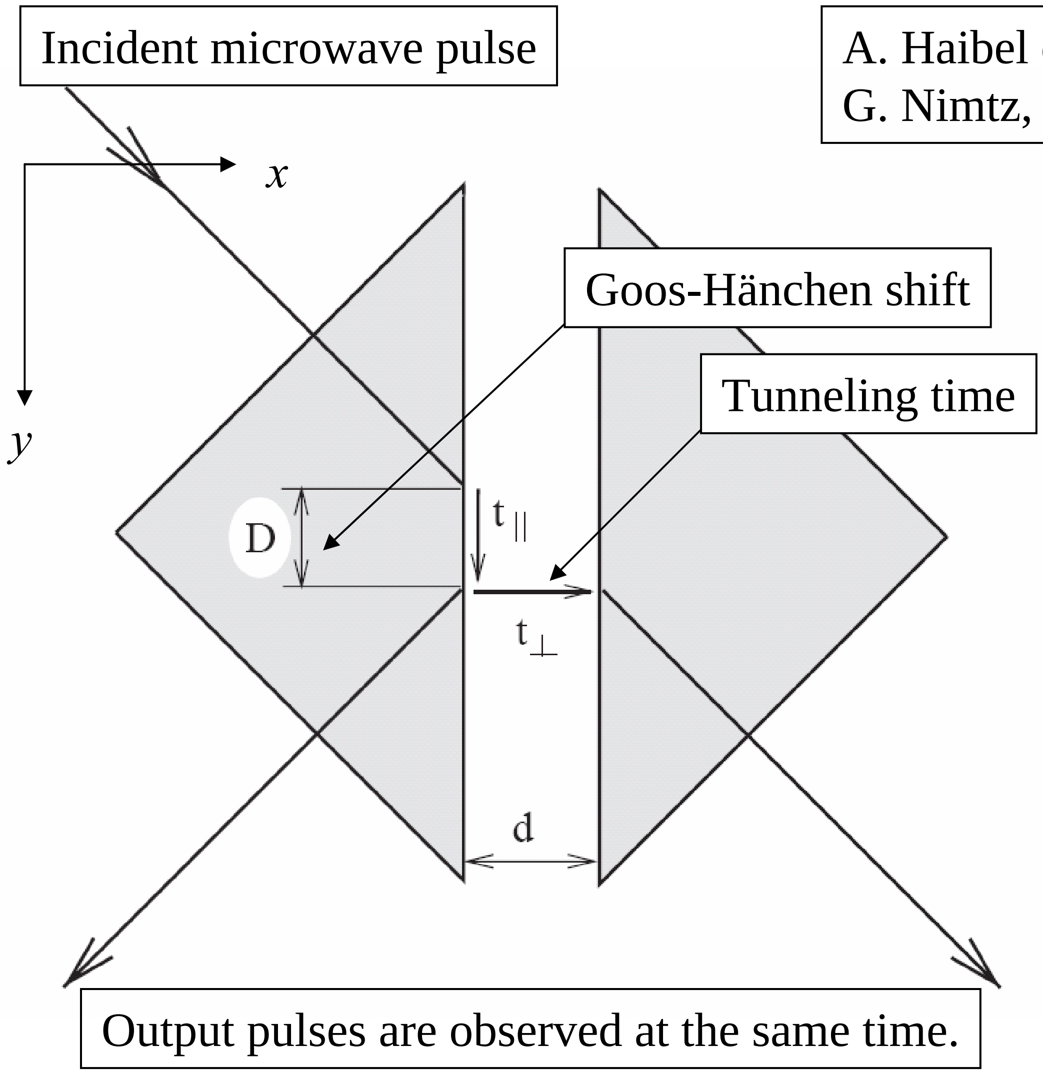
Photonic tunneling is currently of theoretical and applied interest. In a previous review, faster-than-light (i.e. *superluminal*) *photonic tunneling* was discussed (Progr. Quantum Electron. 21 (1997) 81). Recently, superluminal photonic pulse transmission and reflection have been measured at microwave and infrared frequencies. It seems clear that superluminal photonic and electronic devices will become a reality in the near future.

In the present report, we introduce new experimental and theoretical data on superluminal tunneling and reflection. Data of reflection by barriers have evidenced the nonlocal nature of tunneling. Asymmetric barriers have revealed a strange asymmetric reflection behavior in time.

The principle of causality is not violated by a superluminal speed even though the time duration between cause and effect can be shortened compared with a luminal interaction exchange. An empirical relationship independent of the barrier system is found for the photonic tunneling time. This relation seems to be universal for all kind of tunneling processes in the case of single opaque barriers. We show that the superluminal velocity can be applied to speed up photonic modulation and transmission as well as to improve microelectronic devices.

G. Nimtz, Progr. Quantum Electron **27**, 417 (2003)

Experiments by Nimtz et al.



A. Haibel et. al., Phys. Rev. E **63**, 047601 (2001)
G. Nimtz, Progr. Quantum Electron **27**, 417 (2003)

$$k_y = k_t \frac{n_i}{n_t} \sin\theta_i$$

$$D = \frac{\partial \phi}{\partial k_y}$$

Conclusions drawn by Nimtz et al.

- Zero time crossing the gap via tunneling.
- Superluminal propagation of the centre of mass of the pulse.
- Signal velocity faster than *c*.

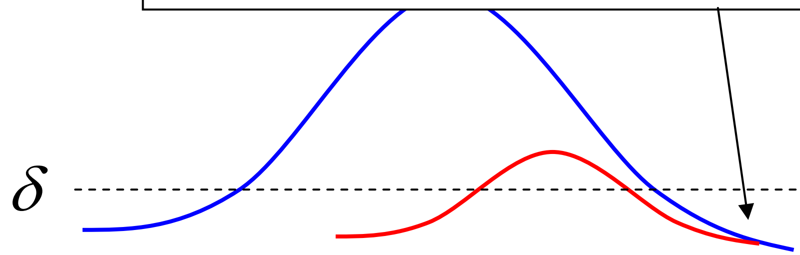
Interpretational issues

- Nimtz claims to have violated the special theory of relativity *“Macroscopic violation of special relativity”*.
- Moreover he suggests that these devices can be utilized to speed up electronic or photonic communication.

Some personal remarks

- Nimtz equates the signal and group velocity…
- Definition of signal arrival*:
  - *"…[provided] one can detect an intensity greater than a limit δ, the signal is said to have arrived."*
- If this criterion is applied then the signal velocity in Nimtz's experiments is < *c*.
- Transmitted pulse does not exceed the envelope of the incident pulse were it to travel at the phase velocity.
- Precursors

Leading edge of pulse is hidden and cannot be used to extrapolate the remaining pulse shape.



* R. L. Smith, *"The Velocities of Light"*, Am. J. Phys. **38**, 978 (1970)

Conclusion

- The experiments performed by Nimtz et al. using FTIR elegantly demonstrate photonic tunneling and have been utilized to generate superluminal centre of mass propagation.
- However, the interpretation that this has lead to *superluminal signal velocity* remains an open question.

- *It may be possible to define the signal velocity utilizing the quantum noise of light as a mechanism which hides precursor information…*