smaria@caltech.edu

Maria Spiropulu

Ph1b Section 05

January 6, 2011

Outline

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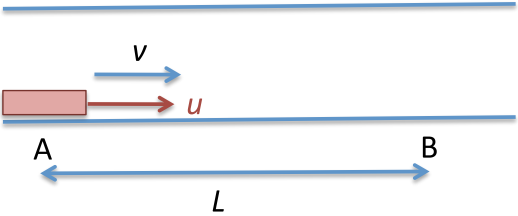
A high school problem

A boat has a speed u km/h relative to the water. It starts at point A on the bank of a river with the stream velocity v Km/h. It moves downstream to the point B on the same bank at a distance L from A, immediately turns back and moves upstream. How long will it take to make the round trip $A \to B \to A$?



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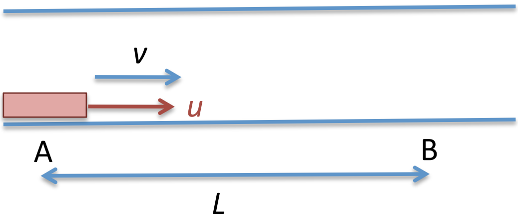

if we assume still water the solution is easy :

$$t_0 = 2\frac{L}{u}$$

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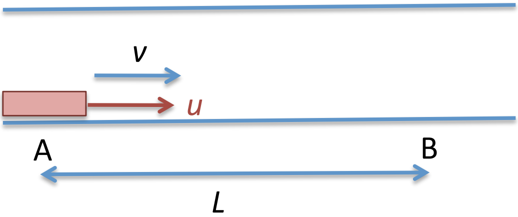

in all generality:

$$t_{\downarrow\uparrow} = t_{AB} + t_{BA} = \frac{L}{u+v} + \frac{L}{u-v} = \frac{t_0}{1-(v^2/u^2)}$$

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Plot $t_{\downarrow\uparrow} = f(v)$

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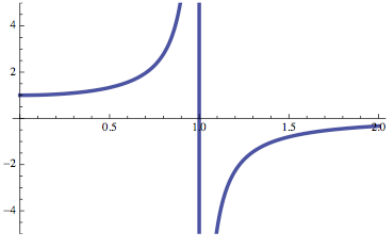

$v < u \Rightarrow t > t_0$

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$v > u \Rightarrow t =$ negative **what's going on?**

$v \sim 0 (v << u) \Rightarrow t \sim t_0$

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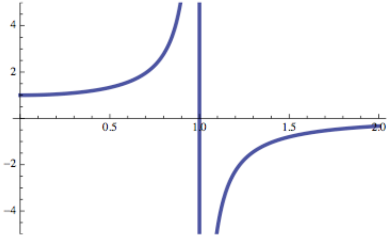

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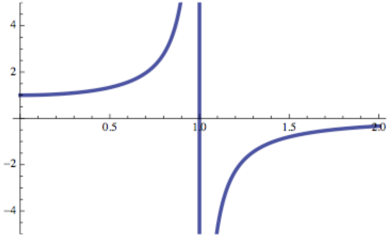

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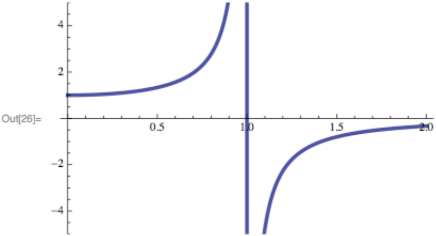

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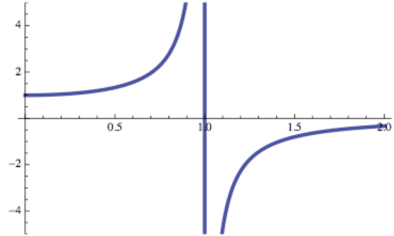

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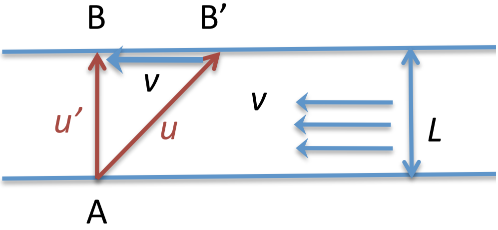

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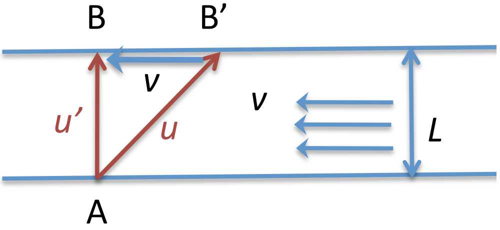

assuming non-zero stream velocity (v) then the boat needs to head to B′ (upstream) in order to get to B; that is to compensate for the drift caused by the stream. Its velocity relative to the water is then u and the boat is directed along AB′.

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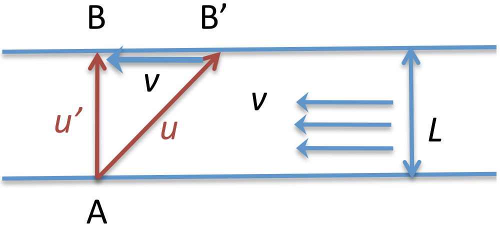

The velocity of the stream is v and directed along B$'$B.

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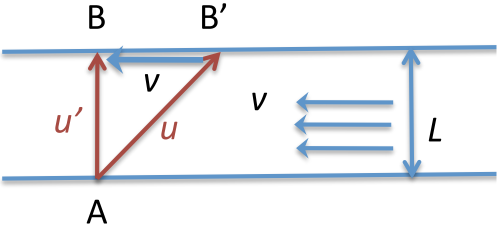

hence

$$u' = \sqrt{u^2 - v^2} = u\sqrt{1 - (v^2/u^2)}$$

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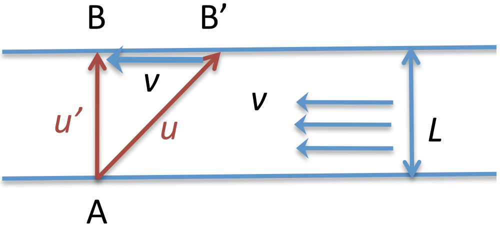

and

$$t_\perp = \frac{2L}{u'} = \frac{2L}{u\sqrt{1-(v^2/u^2)}} = \frac{t_0}{\sqrt{1-(v^2/u^2)}}$$

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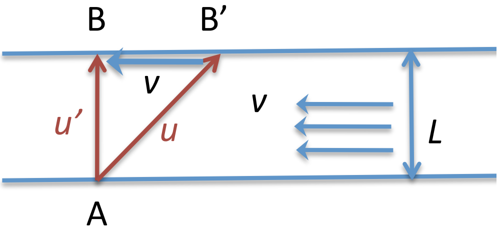

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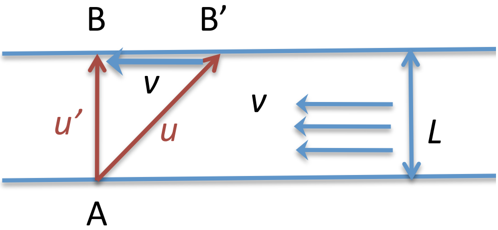

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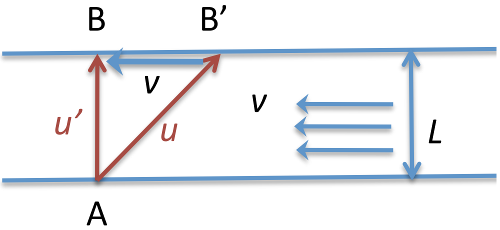

can be $v > u$?

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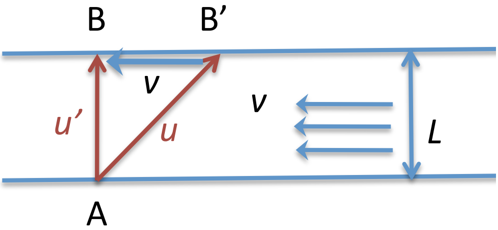

note $t_0 < t_\perp < t_{\downarrow\uparrow}$

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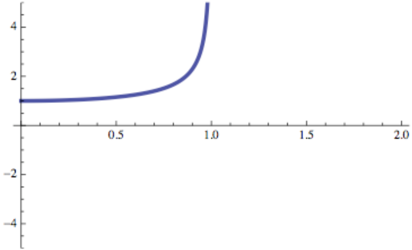

only one branch; (the other is “tachyonic”)

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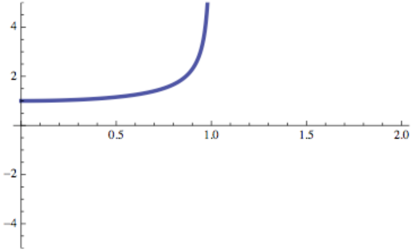

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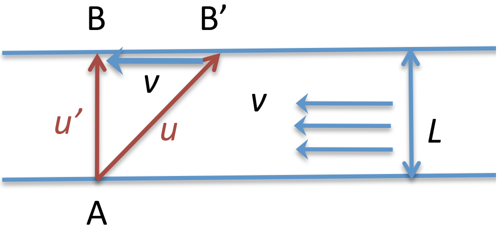

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see Michelson-Morley experiment (chapter 2 Helliwell)

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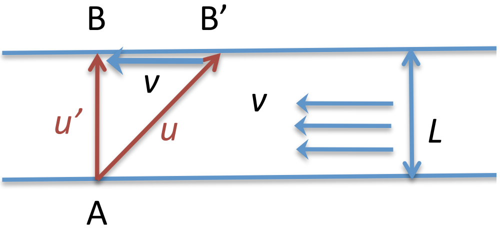

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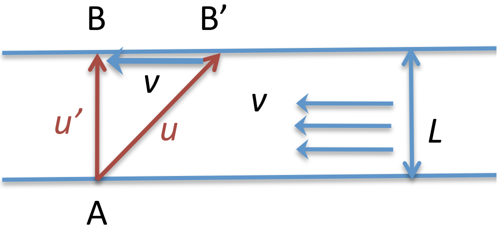

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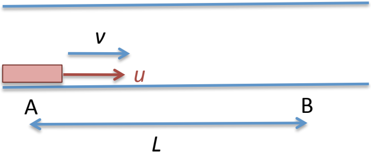

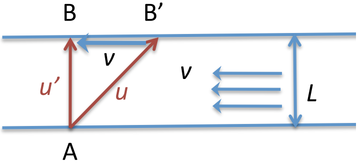

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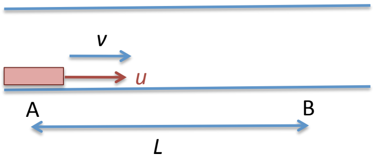

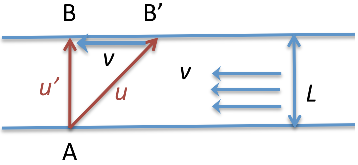

$$(1 - (v^2/u^2))^{-1/2} \sim 1 + \frac{1}{2}\frac{v^2}{u^2} + \ldots$$

$$(1 - (v^2/u^2))^{-1} \sim 1 + \frac{v^2}{u^2} + \ldots$$

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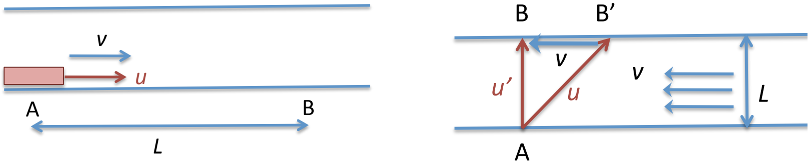

calculate $t_{\downarrow\uparrow} - t_{\perp}$ for $v << u$ with the above approximations

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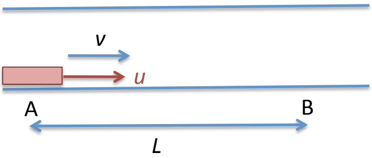

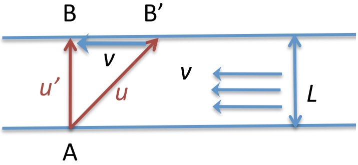

what about gravity waves? (look-up the LIGO design)

Outline

Prelude

Relativity

Logistics

Electromagnetism, light and Albert E.

- "special relativity" emerged from attempts to reconcile the electromagnetic theory with experimental data involving moving bodies.
- If we assert Coulomb's law as an axiom then we can get all the rest of electromagnetism from relativity.
- Classical theory of electricity concepts: electric charge q, and electric field E. These two are related by Gauss' law.
- what about magnetism? there are no magnetic charges (monopoles) so where does magnetism come from?
- an electric charge in motion produces the magnetic field. But the "state of motion" is not an intrinsic characteristic of the charge; it depends on a **reference frame.**

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- we will see how all this works in the second part of this course, namely E&M
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- **take home point II** electromagnetism (Maxwell's equations) predict that the electromagnetic waves propagate at the **speed of light** $c \sim 3 \times 10^8 m/s$
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- **take home point I** the "relativity" ideas were developed/instigated by electromagnetic phenomena at the end of the 19th and the beginning of 20th century.
- **take home point II** electromagnetism (Maxwell's equations) predict that the electromagnetic waves propagate at the **speed of light** $c \sim 3 \times 10^8 m/s$
- **take home point II** *nothing will come out of nothing* Shakespeare, King Lear

Electromagnetism, light and Albert E.

- **all magnetic fields can be considered as a purely relativistic effect.** too simplistic
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Principles

The principle of special relativity & the principle of the constancy or invariance of the speed of light

- All reference frames in rectilinear, uniform and irrotational motion, i.e. the so-called **inertial reference frames** shall be completely equivalent in physics. No inertial frame shall be distinguished from any other inertial frame by any property.
- The speed of light in the vacuum has the same value in each inertial frame, irrespective of the velocities of the light source or the light receiver. **it is a fundamental physics constant** c**=299,792,458 m/s**
- **March challenge (4U): write an essay titled "if $c = 45$ km/h the world would look like this:" (you will need to be quantitative)**
- **Q(4U):To what accuracy has the speed of light been measured?**
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Not the speed of light

- the speed of light is **absolute** : c=299,792,458 m/s

In 1987 a supernova explosion happened in the large Magelanic cloud 165,000 light years away (1ly =9.5×10^{15} =m). Neutrinos, almost massless particles that travel with the speed of light, were emitted from the different nuclei (that had different velocities by as much as 10,000 km/s). All neutrinos and photons arrived within 10 s.

Physics Letters B
Volume 201, Issue 3, 11 February 1988, Pages 353-354

doi:10.1016/0370-2693(88)91154-9 | How to Cite or Link Using DOI

The speed of light and the speed of neutrinos

Leo Stodolsky
Max-Planck-Institut für Physik und Astrophysik - Werner-Heisenberg-Institut für Physik, P.O. Box 40 12 12, D-8000, Munich, Fed. Rep. Germany
Received 4 November 1987. Available online 16 October 2002.

Abstract

The approximate equality in the arrival times of the neutrino and light signals from SN 1987A allows an accurate check of the hypothesis of special relativity that the limiting velocity for all forms of radiation is the same.

Article Outline

- References

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Time is Relative

Of all inertial observers, an observer at rest relative to a process measures the shortest time for that process. This time is called the *proper time* of the process and is denoted by τ (t')When a frame in motion (prime frame) at a contant velocity v relative to another frame (unprimed frame), any process (such as the tick of the clock) being at rest in the frame of motion, and requiring time t' in this prime frame, is lengthened for an observer at rest in the unprimed frame

$$t = \frac{t'}{\sqrt{1-(v^2/c^2)}} = \frac{t'}{\sqrt{1-\beta^2}} = \gamma t' \geq t'$$

where

$$\beta = \frac{v}{c}, \quad \gamma = \frac{1}{\sqrt{1-\beta^2}}$$

This is called time dilation, literally time stretching

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This is called time dilation, literally time stretching

Time is Relative

In 1971 time dilation was measured in the Hafele-Keating Experiment where two very precise atomic clocks went on two jets around the earth in different routes (eastbound and westbound).

Science 14 July 1972:
Vol. 177 no. 4044 pp. 166–168
DOI: 10.1126/science.177.4044.166

‹ Prev | Table of Contents | Next ›

Around–the–World Atomic Clocks: Predicted Relativistic Time Gains

J. C. Hafele and Richard E. Keating

± Author Affiliations

ABSTRACT

During October 1971, four cesium beam atomic clocks were flown on regularly scheduled commercial jet flights around the world twice, once eastward and once westward, to test Einstein's theory of relativity with macroscopic clocks. From the actual flight paths of each trip, the theory predicts that the flying clocks, compared with reference clocks at the U.S. Naval Observatory, should have lost 40 ± 23 nanoseconds during the eastward trip, and should have gained 275 ± 21 nanoseconds during the westward trip. The observed time differences are presented in the report that follows this one.

‣ Science 14 July 1972: Vol. 177 no. 4044 pp. 166-168

Time is Relative

Decaying sub-atomic particles are like very fast moving clocks. In their rest frame they decay with proper time τ while an observer at rest measures the time of their decay to be $\gamma\tau > \tau$.
A great example is that of the atmospheric muons that have proper decay time 1.4μ but on earth we measure their decay time to be ?
$(v = 0.994c \Rightarrow \gamma = 9 \Rightarrow t = 14\mu \Rightarrow L = ?)$

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And what about space?

The views of space and time which I wish to lay before you have sprung form the soil of experimental Physics and thein lies their strength. They are radical. Henceforth space by itself and time by itself are doomed to fade away into mere shadows and only one kind of union of the two will preserve an independent reality Minkowski 1908

will continue on Monday

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Outline

Logistics

Prof. Spiropulu, http://www.hep.caltech.edu
Office 265 Lauritsen, x2471, x6676, x6667
Notes and other material/workbooks references etc will be posted in the 05 Section twiki
https://twiki.hep.caltech.edu/twiki/bin/view/Main/Smaria
(starting next week)
A student twiki will be set there for you (and an account)
Dr. Dorian Kcira dkcira@caltech.edu is managing the twiki and will be sending you info on the account

Reference Frames and Coordinate systems

- Reference frame is usually (but not always) a physical rather rigid object to which we refer our measurements and observations (car train plane, spaceship, the earth, the galaxy, even a cluster of galaxies etc)
- A Coordinate system is a way we specify a position by assigning to it a set of numbers (Cartesian, spherical, cylindrical etc); Geometrically thay can be represented as a triad of unit vectors $\hat{\vec{x}}$, $\hat{\vec{y}}$, $\hat{\vec{z}}$. A point in space is specified by the orthogonal projections of its position vector onto the corresponding directions.
- There are infinite such triads we can devise. They are all distinct and they can all be obtained from another by appropriate rotations and/or reflections.
- A reference frame and a coordinate system are different concept and specifically the former does not specify the latter

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Newtonian space and time (from Principia)

- Absolute space in its own nature, without regard to anything external, remains always similar and immovable
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Dark Matter Physics Colloquium today

PHYSICS RESEARCH CONFERENCE
Thursday, January 6, 2011
201 E. Bridge, 4 pm
Refreshments served in 114 E. Bridge at 3:45 pm
http://www.pma.caltech.edu/∼physcoll/PhysColl.html
Neal Weiner
Associate Professor of Physics, New York University
"The Force of the Dark Side"

While evidence for the existence of dark matter has grown over the past two decades, information on what it actually is remains elusive. Conventional ideas have been limited to a single, largely non interacting particle to make up the majority of the matter of the universe. Of late, a series of results from astrophysics and direct detection experiments have prompted an explosion of new ideas for dark matter, including new forces, excited states, and light WIMPs. I will review what has prompted these new ideas, and why they have changed how we think about other signatures of dark matter, such as would show up at colliders. Finally, I will discuss what experiments in the near future will clarify these questions, and let us know if we have finally begun to probe the dynamics of the dark sector.