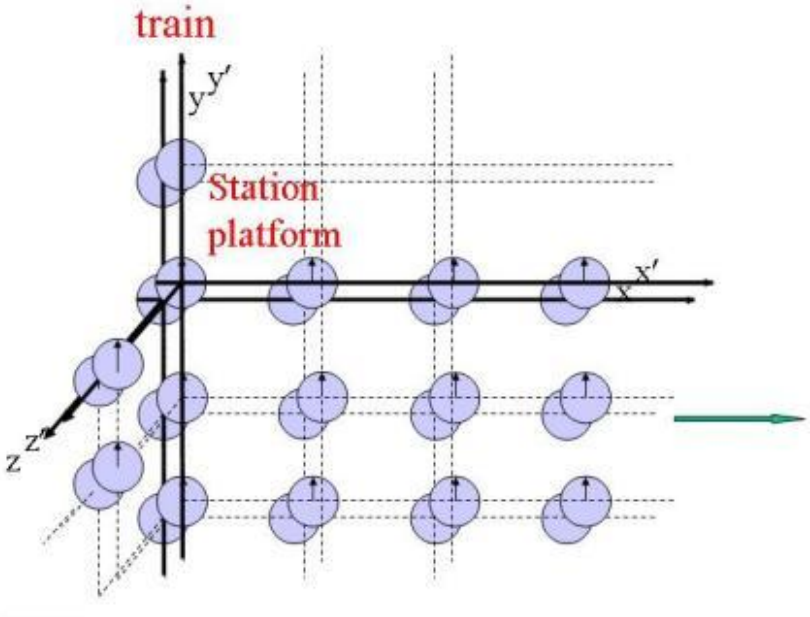
1. Announcement

Announcement

- Exams
  - March 2
  - April 6
  - Final May 5

2. Lecture 5: Time and Space Relative: Slide 2



3. Special Relativity

Special Relativity

- Einstein (1905 Miraculous Year!) required
  - Laws of Physics are independent of inertial frame *or* one can not detect absolute motion
    Think about being on a moving train.
  - Speed of light (**c**) is independent of the motion of the source *or* c is velocity of EM wave in any inertial frame (c=300,000,000 m/s or 186,000 miles per second)
    Think about ultimate speed. Also no ether.
- 2 innocent requirements. Can these be compatible?
  - Construct a light clock

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4. Miraculous year 1905

Miraculous year 1905

- 26 yrs - doctorate - patent office ('02-'08) - married since '03 to Mileva Maric (Serbian, met at ETH-Zurich) 2 children, Lieserl('02?) & Hans Albert('04)
- 5 papers that changed physics (& understanding & the world)!
  - On the Electrodynamics of Moving Bodies (***space-time relativity***)
  - Does the Inertia of a Body Depend on Its Energy Content? (***$E=mc^2$***)
  - On a Heuristic Point of View Concerning the Production and Transformation of Light (***photons & photoelectric effect***)
  - On the Movement of Small Particles Suspended in Stationary Liquids Required by the Molecular-Kinetic Theory of Heat (***Brownian motion***)
  - A New Determination of Molecular Dimensions (dissertation - calculates ***Avogadro's number & size of molecules***)
- Genius! Independence, creativity, self-confidence, depth of understanding, persistence, assimilation of contemporary progressive culture, skepticism

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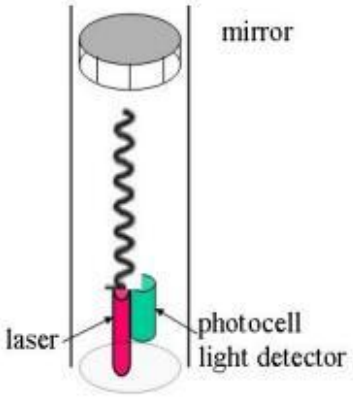
5. Construct light clock

Construct light clock



Light hits mirror & reflects back
To go 1 meter takes
$1/(3.0\times10^{8}\text{m/sec})$
$=3.3\times10^{-9}$ sec
=3.3 nanoseconds

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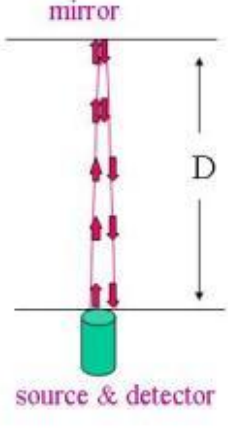
6. Light clock - accurate time keeper

Light clock - accurate time keeper

Bouncing light beam

Time for 1 tick
time for one round
trip of light
[*or* $2\times D/(\text{speed of light})$]
(put on train - primed frame of ref.)
ex: D=1m so $\Delta t' = 2\text{m}/(3\text{x}10^{8}\ \text{m/s})$
$= 0.67\text{x}10^{-8}$ s
= 6.7 nanosec

if $c' = 3\text{x}10^{8}$ m/s - but why?



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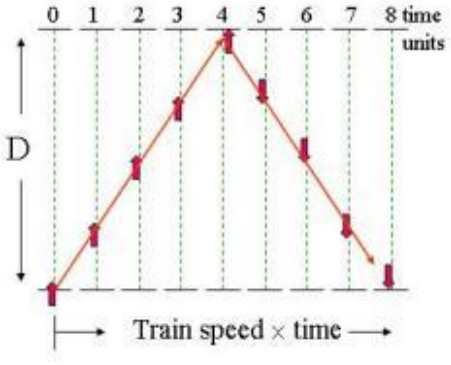
7. Light clock on fast moving train seen from platform

Light clock on fast moving train *seen* from platform



Light clock moves right at train speed while light pulse travels up & down between source & mirror

Light's up & down path, at light speed, covers more distance than 2 × D

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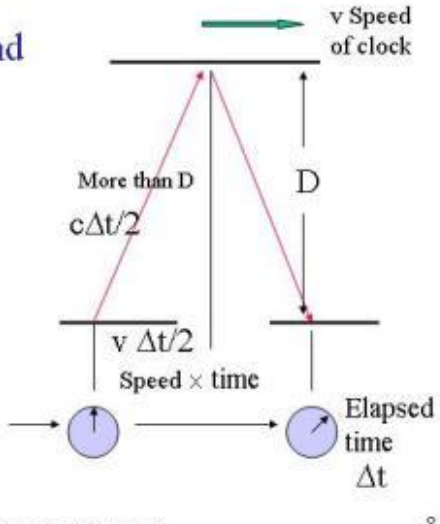
8. Moving light clock

Moving light clock

- In moving clock frame of reference S one round trip is one time unit.
- $\Delta t = 2D/[c\sqrt{(1-v^2/c^2)}]$

from PythagorianTheorem (see next slide for algebra)

- Compare with synchronized clocks in stationary frame.



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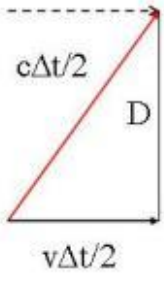
9. Time in Station frame

Time in Station frame

In time $\Delta t/2$ upper mirror has moved distance $v\Delta t/2$ and light beam has met the mirror, so follows red, slanted path.



Pythagorian Theorem: $\left(c\frac{\Delta t}{2}\right)^2 = D^2 + \left(v\frac{\Delta t}{2}\right)^2$

so $\frac{1}{4}c^2\Delta t^2 = D^2 + \frac{1}{4}v^2\Delta t^2$ **or** $c^2\Delta t^2 = 4D^2 + v^2\Delta t^2$

Collecting Δt terms: $4D^2 = c^2\Delta t^2 - v^2\Delta t^2 = (c^2 - v^2)\Delta t^2$

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

Take square root: $2D = c\sqrt{\left(1 - \frac{v^2}{c^2}\right)}\ \Delta t$

Hence $\Delta t = \frac{2D}{c\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$ **is time elapsed in S frame**

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10. Compare 2 views of light clock

Compare 2 views of light clock

$$\text{In S}': \Delta t' = \frac{2D}{c'}$$

$$\text{In S}: \Delta t = \frac{2D}{c\sqrt{1 - \frac{v^2}{c^2}}}$$

For sound wave or water wave $c\sqrt{(1-v^2/c^2)}=c'$
But Einstein says c is same in all inertial frames!

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11. Puzzle and resolution

Puzzle and resolution

- How can c ′ = c? Only if $\Delta t' \neq \Delta t$!!
- Need $\Delta t = \Delta t' \ / \ \sqrt{(1-v^2/c^2)} > \Delta t'$
- Moving clock "runs slow"
  - i.e. time interval from sending to receiving light signal is longer in moving frame S
- Time is relative!!!!!
  - Time interval is shortest in S ′, frame in which clock is at rest
    $\Delta t = \Delta t_0$ proper time
- Consider the decaying muon 2.2×10^{-6} s at rest
  For v=0.999c get $1-v^2/c^2 = 1.999 \times 10^{-3}$.
  So $\sqrt{(1-v^2/c^2)} = 4.471 \times 10^{-2}$ and
  $\Delta t = 2.2 \times 10^{-6} \div 4.471 \times 10^{-2} = 4.9 \times 10^{-5}$ sec
  Hence it lives 22 times longer
  & travels $d = 4.9 \times 10^{-5}$ s $\times$ 3.0×10^8 m/s = 1.5×10^4 m = 15 Km

$$\Delta t = \frac{\Delta t'}{\sqrt{1 - \frac{v^2}{c^2}}}$$

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12. Compare 2 views of light clock

Compare 2 views of light clock

In train passenger view, light covers a round trip distance of 2 ×D. ⟷ Time elapsed is 2 ×D ÷ speed of light

In station platform view, light travels greater distance from source to receiver. ⟷ Time elapsed is 2 ×largerD ÷ speed of light

For water wave in moving water current, the speed of the wave (relative to shore) will be greater than in still water. Round trip will cover greater distance, but faster, so elapsed time from start to finish is same measured on-shore or in boat moving with current. (airplane & wind)
But Einstein says c is same in all (inertial) frames!

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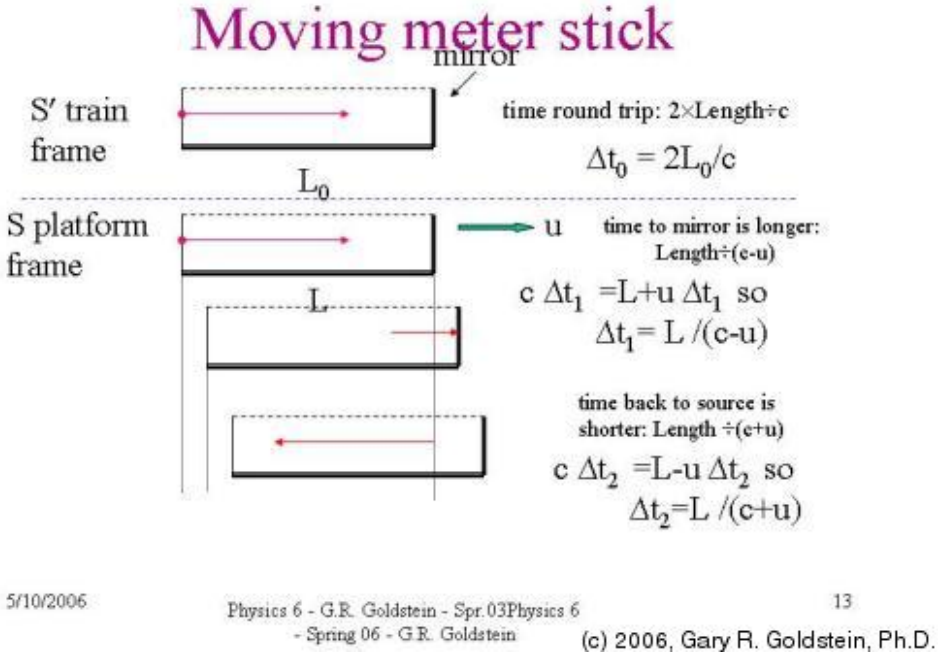
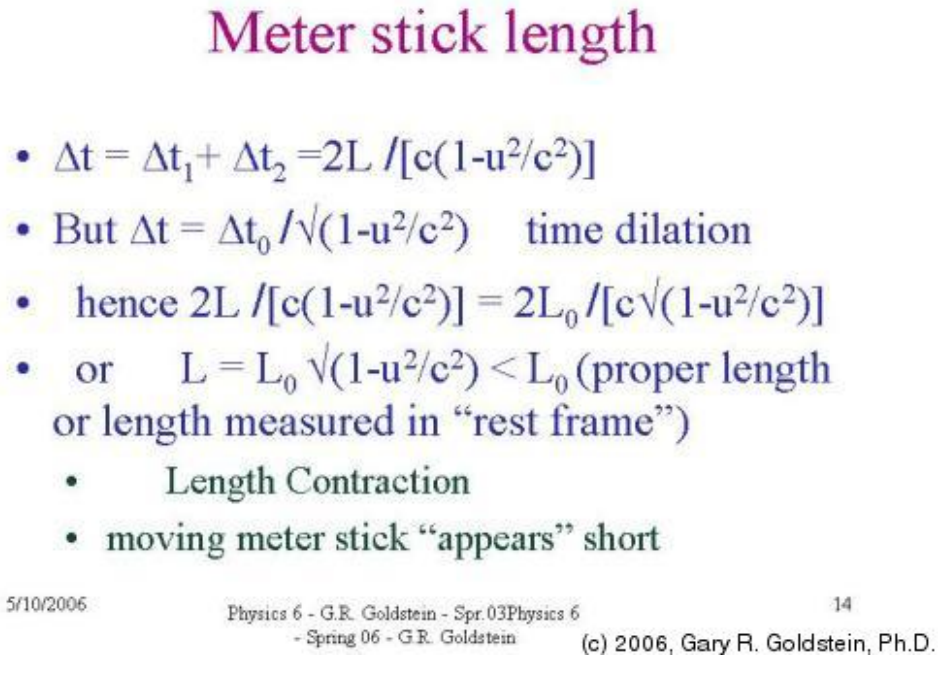
13. Moving meter stick



14. Meter stick length



15. Lecture 5: Time and Space Relative: Slide 15

Einstein's notes attempting to explain length contraction and time dilation to David Rothman without math!

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Sept.1939 - The above calculations are in Prof. Einstein's own hand, used to explain to me without the use of mathematics the reason for the contraction of a rod in the direction of its motion and why a clock changes its rhythm.
David A. Rothman

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